SEP 21 1922

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# ENGINEERING:

## An Illustrated Weekly Journal.

*EDITED BY WILLIAM H. MAW AND ALEX. RICHARDSON.*

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**Aveling & Porter, Ltd.,**
ROCHESTER. 9663

**Steam Road Rollers & Tractors.**

**A. G. Mumford, Ltd.,**
CULVER STREET WORKS, COLCHESTER.
ON ADMIRALTY AND WAR OFFICE LISTS.
ENGINES for Torpedo Boats, Yachts, Launches.
BOILER FEED PUMPS.
See advertisement pages 24 and 25.
PATENT WATER-TUBE BOILERS,
AUTOMATIC FEED REGULATORS.
And Auxiliary Machinery as supplied to the Admiralty. 2179

**Dredging Plant**
OF ALL DESCRIPTIONS.
FLOATING CRANES. COAL BUNKERING VESSELS.
Werf Conrad, HAARLEM, HOLLAND.
Agents: MARINE WORKS, LTD., FRIARS HOUSE, 39-41, NEW BROAD ST., LONDON, E.C.2.
*See half-page Adver. last week and next week.* 675

**Cranes.—Electric, Steam,**
HYDRAULIC and HAND,
of all types and sizes.
GEORGE RUSSELL & CO., LTD., Motherwell, near Glasgow. 9048

STEEL TANKS, PIPES, GASHOLDERS, &c.
**Thos. Piggott & Co., Limited,**
BIRMINGHAM. 7411
See Advertisement last week, page 39.

**"Spencer-Hopwood" Patent WATER TUBE Boilers.** *See page 39.* 577
Sole Makers: SPENCER-BONNECOURT, LTD., Parliament Mansions, Victoria St., London, S.W.

**Tank Locomotives.**
Specification and Workmanship equal to Main Line Locomotives.
R. & W. HAWTHORN, LESLIE & CO. LTD., ENGINEERS, NEWCASTLE-ON-TYNE. 9044

**Cochran** MULTITUBULAR AND CROSS-TUBE TYPES. **Boilers.**
See page 17. 9047

**Petter Oil Engines.**
For Paraffin and Crude Oil.
Sizes 1½ B.HP. and upwards.
**Petters Limited, Yeovil.**
Sizes 25 to 500 B.HP.
**Vickers-Petters, Ltd., Ipswich**
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*BUTTERWORTH BROS., Ltd., Newton Heath Glass Works, Manchester.* Od 9783

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9662
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SPECIALISTS in the SALE AND VALUATION of PLANT AND MACHINERY and ENGINEERING WORKS.
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**Tubes and Fittings.**
Sole Licensees in Great Britain for the manufacture of "Armco" Rust and Corrosion Resisting Iron Tubes. 817
**The Scottish Tube Co., Ltd.,**
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See Advertisement page 78, Sept. 1.

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PASSENGER AND CARGO STEAMERS,
SHALLOW DRAFT VESSELS. 818

**Campbells & Hunter, Ltd.**
Gear Cutting.
Worm Wheels cut up to 13 ft. diam.
Bevel and Mitre Wheels planed up to 3 ft. diam.
Spur Wheels cut up to 9 ft. diam.
DOLPHIN FOUNDRY, LEEDS. 4847

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PORTSMOUTH.
SHIP & LAUNCH BUILDERS, Od 3581
ENGINEERS & BOILER MAKERS,

**Cement.—Maxted & Knott,**
LTD., Consulting Cement Engineers, ADVISE GENERALLY on proposed Cement Schemes FOR ENGLAND AND ABROAD. ADVICE ONLY. Highest references. Established 1900.
Address, BURNETT AVENUE, HULL.
Cablegrams: "Energy, Hull." 9782

**OIL FUEL APPLIANCES,**
*Systems*
PRESSURE, AIR, STEAM
*For Boilers of all types.*
KERMODES LIMITED,
35, The Temple, Dale Street, Liverpool.
*Naval Outfits a Speciality,* also for Merchant Ships, for Factories, Locomotives, and Industrial Process Furnaces of all kinds.
Supplied to the British and other Governments.
Telephone No.: Central 2832.
Telegrams: "Warmth." 4078

**Locomotives Tank Engines**
designed and constructed by
MANNING, WARDLE AND COMPANY, LIMITED, Boyne Engine Works, Leeds. Od 2487
See their Illus. Advertisement, page 93, last week.
RAILWAY AND TRAMWAY ROLLING STOCK.
**Hurst, Nelson & Co., Ltd.**
THE GLASGOW ROLLING STOCK AND PLANT WORKS, MOTHERWELL. Od 2582

**R. Y. Pickering & Co., Ltd.,**
(ESTABLISHED 1864.)
BUILDERS of RAILWAY CARRIAGES & WAGONS.
MAKERS of WHEELS and AXLES of all kinds.
RAILWAY WAGONS FOR HIRE.
Chief Works and Offices:
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London Office: Od 3363
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**Henry Butcher & Co.,**
AUCTIONEERS, VALUERS AND SURVEYORS for ENGINEERING AND ALLIED TRADES and INDUSTRIAL PROPERTIES. 9666
63 and 64, CHANCERY LANE, LONDON, W.C.2.

**Electric Transporters.**
S. H. HEYWOOD & CO., LTD., 9662
REDDISH.

**John H. Wilson & Co., Ltd.,**
Birkenhead.
See Illustrated Advertisement Page 100, Jan. 28, 1921.

**Locomotive Shunting Cranes**

**Steam and Electric Cranes**
EXCAVATORS, CRANE-HAVVIES, GRABS, CONCRETE-MIXERS,
SHIPS' WINDLASSES, WINCHES, and DECK MACHINERY. 667
LISTS OF STANDARD SIZES ON APPLICATION.
London Office: 15, VICTORIA STREET, S.W.1.

**John Bellamy, Limited,**
MILLWALL, LONDON, E. 1216
GENERAL CONSTRUCTIONAL ENGINEERS,
**Boilers, Tanks, & Mooring Buoys**
STILLS, PETROL TANKS, AIR RECEIVERS, STEEL CHIMNEYS, RIVETED STEAM AND VENTILATING PIPES, HOPPERS, SPECIAL WORK, REPAIRS OF ALL KINDS.

IRON & STEEL
**Tubes AND Fittings AND Steel Plates.**
**Stewarts and Lloyds, Ltd.**
GLASGOW - BIRMINGHAM - LONDON.
See Advertisement Page 57. 9663

**Economy!**
HIGH BOILER EFFICIENCIES ARE OBTAINED BY INSTALLING
**Todd Oil Burners**
FUEL OIL BURNING SYSTEMS, HEATERS, STRAINERS.
49-51, EASTCHEAP, LONDON, E.C. 3.
TODD SHIPYARDS CORPORATION,
Builders of Steam and Motor Ships, Repairers, Electric Drive Installations.
Twenty-one Floating Docks, Two Graving Docks, Twelve shipways.
25, Broadway, New York, U.S.A. 9660

**The Glasgow Railway Engineering Company,**
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London Office—13, Victoria Street, S.W.
MANUFACTURERS OF
RAILWAY CARRIAGE, WAGON & TRAMWAY WHEELS & AXLES,
CARRIAGE & WAGON IRONWORK, also CAST-STEEL AXLE BOXES. 640

SPECIFY WELDLESS STEEL CHAIN.
**The Strongest Chain** 898
IN THE WORLD.
Sole Manufacturers: WELDLESS CHAINS, LTD., 50, WELLINGTON STREET, GLASGOW.

**Brett's Patent Lifter Co.** LIMITED.
**Hammers, Presses, Furnaces,**
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**Hurst, Nelson & Co., Ltd.,**
Builders of RAILWAY CARRIAGES, WAGONS, ELECTRIC CARS, and EVERY OTHER DESCRIPTION OF RAILWAY and TRAMWAY ROLLING STOCK.
Makers of WHEELS and AXLES, RAILWAY PLANT, FORGINGS, SMITH WORK, IRON & BRASS CASTINGS, PRESSED STEEL WORK OF ALL KINDS.
Registered Office and Chief Works: Motherwell.
London Office: 14, Londenhall Street, E.C. Od3382

**Electric Lifts**
(UP TO 25 TONS.)
9662
S. H. HEYWOOD & CO., LTD. REDDISH.

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Any class of tools. H. S. Chasers for adjustable die heads. Case hardening, colouring, etc. We can case harden Cast Iron for gauges, press tools, etc. Write us for particulars. Reliable Work! Right Prices! Delivery to promise!
OWEN & CRISP,
Engineers and Engineers' Agents,
64, Basinghall Street, London, E.C. 2.
Telephone:—London Wall 5666. 9660

**Diesel Engines, Six Cylinder,**
Two and Four stroke, 350, 1000, 1200 HP., excellent condition. Dynamos for above 250 or 500 volts, D.C. Immediate delivery and low price.
Two 500 Kw. Parsons Turbine Sets, 250 or 500 volts, D.C., with condensing plant and spare armature. Price £2300.
Electrical driven Centrifugal, Ram and other Pumps from 1½ in.-10 in. outlet.
JENNINGS,
West Walls, Newcastle-on-Tyne. 9749

**Royles Limited,**
ENGINEERS, IRLAM, MANCHESTER.
FEED WATER HEATERS, CALORIFIERS, EVAPORATORS, CONDENSERS, AIR HEATERS, Merrill's Patent TWIN STRAINERS for Pump Suctions, } ROW'S PATENTS.
SYPHONIA STEAM TRAPS, REDUCING VALVES
High-class GUNMETAL STEAM FITTINGS.
WATER SOFTENING and FILTERING. 8723

**YARROW & CO. (1922), LTD., GLASGOW.**
LAND AND MARINE
YARROW BOILERS. 819

**Matthew Paul & Co., Ltd.**
LEVENFORD WORKS, **Dumbarton.** 763
See Full Page Advt., page 56, Aug. 18.

**Forgings.**
**Walter Somers, Limited,**
HALESOWEN. 7116

**Taylor & Challen Presses**
About 200 NEW PRESSES in Stock in our Showrooms for immediate delivery at specially Reduced Prices.
TAYLOR & CHALLEN, LTD., Engineers, Constitution Hill, BIRMINGHAM.
See Full page Advertisement, page 59, Aug. 18.

**Head, Wrightson & Co.,**
LIMITED.
See Advertisement page 66. 3403

**Railway Switches and Crossings.**
T. SUMMERSON & SONS, LIMITED, DARLINGTON. 666

GRAPHITED OIL. **"OILDAG"** (Reg.) BRAND.
GRAPHITED WAYNE. **"AQUADAG"** (Reg.) BRAND.
GRAPHITED GREASE. **"GREDAG"** 747
**E. G. Acheson Ltd.,**
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**Locomotive Traversers**
(ELECTRIC).
9662
S. H. HEYWOOD & CO., LTD., REDDISH.

**P. & W. MacLellan, Limited,**
CLUTHA WORKS, GLASGOW.
MANUFACTURERS OF
RAILWAY CARRIAGES AND WAGONS
OF EVERY DESCRIPTION.
RAILWAY IRONWORK, BRIDGES, ROOFING, &c.
Chief Offices: 139, Trongate, GLASGOW. Od 3547
Registered Offices: Clutha House, 10, Princes St., Westminster, London, S.W.1.

**Centrifugals.**
**Pott, Cassels & Williamson,**
MOTHERWELL, SCOTLAND. 9737
See half-page Advertisement page 63, Sept. 1.

## The Manchester Steam Users' ASSOCIATION.

For the prevention of Steam Boiler Explosions and for the attainment of Economy in the Application of Steam. 9, MOUNT STREET, MANCHESTER.
Chief Engineer: C. E. STROMEYER, M.I.C.E.
Founded 1854 by SIR WILLIAM FAIRBAIRN.
Certificates of Safety issued under the Factory and Workshops Act, 1901. Compensation for Damages and Liabilities paid in case of Explosions. Engines and Boilers inspected during construction. 598

## University of Birmingham.

CIVIL ENGINEERING DEPARTMENT.

PROFESSOR: F. C. LEA, D.Sc., M.Inst.C.E., M.Inst.M.E.

Courses in Civil Engineering, including Hydro-Electric Engineering leading to the B.Sc. Degree (exempting from the examinations of the Institution of Civil Engineers), will commence in October.
Special Courses are also provided in Town Planning and Civic Design.
Further particulars can be obtained from the SECRETARY or from the PROFESSOR of CIVIL ENGINEERING. W 155

## The Polytechnic, 309, Regent STREET, W. 1.

A SPECIAL COURSE has been arranged for students taking the Graduateship Examination of the Institution of Mechanical Engineers, the Preliminary Examination of the Institution of Civil Engineers, and the Final Examination of the Institution of Electrical Engineers.
The classes are as follows:—

| | | |
|---|---|---|
| PURE MATHEMATICS | Friday, | 6.30—9.0. |
| ENGLISH | ,, | 8.0 —9.30. |
| MECHANICS | Thursday, | 6.30—8.0. |
| FRENCH | ,, | 8.0 —9.30. |
| PHYSICS | Wednesday, | 6.30—9.0. |

The syllabus covers all the work in these subjects required for the examinations mentioned.
Fee for the Course, £2 2s.
Prospectus, 2d. post paid, from the DIRECTOR OF EDUCATION, W 169

## The Polytechnic, Regent St., W. 1. SCHOOL OF ENGINEERING.

President of School:
The Hon. SIR CHARLES PARSONS, K.C.B., M.A., LL.D., D.Sc., F.R.S., &c.
Head of Department:
ALEX. R. HORNE, O.B.E., B.Sc. (Hons. Eng.), F.R.S. (Brit.), &c.

The DAY DEPARTMENT re-opens on SEPTEMBER 19th. Entrance Examination commences September 12th, at 9.30 o'clock.
Three year DIPLOMA COURSES in—
MECHANICAL ENGINEERING.
ELECTRICAL ENGINEERING.
MOTOR CAR ENGINEERING.
CIVIL ENGINEERING.
Practice in the Laboratories, Drawing Office, Workshop and Field.
Fee 31 Guineas per annum.
The EVENING DEPARTMENT re-opens on September 25th. Students enrolled from September 13th, 6 to 8.30 p.m.
The Day or Evening Courses are recognised for the Diplomas and Certificates issued by the Institution of Mechanical Engineers in conjunction with the Board of Education.
Detailed prospectus of Day or Evening Department, 2d., post paid, from the DIRECTOR OF EDUCATION. W 136

## The Sir John Cass Technical INSTITUTE.

JEWRY STREET, ALDGATE, E.C. 3.

Principal:—
CHARLES A. KEANE, D.Sc., Ph.D., F.I.C

DEPARTMENT OF METALLURGY.

Evening Classes for those engaged in Metallurgical Industries, Prospectors, those intending to take up Metallurgical Work in the Colonies, Engineers, and Works' Analysts.

STAFF:—
Head of the Department:—
GEO. PATCHIN, A.R.S.M., M.I.M.M.

Lecturers:—
W. A. C. NEWMAN, B.Sc., A.R.S.M., F.I.C.
O. F. HUDSON, D.Sc., A.R.C.S.
L. SINGLEHURST WARD, B.Sc.
W. R. SCHOELLER, Ph.D., A.I.C.
R. G. BATSON, A.M.I.C.E., M.I.M.E.
W. J. BURTON, O.B.E.
A. F. GIBBS.

The following Courses of Lectures, accompanied by suitable laboratory work, will be given during the session:—
Metallurgy of Gold, Silver, Lead, etc.
Assaying—Mineralogy.
Metallurgy of Iron and Steel.
Metallography—Foundry Practice.
Heat Treatment of Metals and Alloys.
Mechanical Testing of Metals and Alloys.
Analysis of Engineering Works Material.
Mechanical Drawing—Materials of Construction.

NEW SESSION commences MONDAY, SEPTEMBER 25th, 1922.
ENROLMENT WEEK—Monday, September 18th to Friday, September 22nd—6.30 to 8.30 p.m.
Detailed Syllabus may be had upon application at the Office of the Institute, or by letter to the PRINCIPAL. W 160

## Battersea Polytechnic, LONDON, S.W. 11.

Principal: ROBERT H. PICKARD, D.Sc., F.R.S.
ENGINEERING DEPARTMENT.
Evening Classes suitable for Final B.Sc. (Eng.), A.M.I.C.E., A.M.I.M.E., &c., are held in the following subjects:—
Strength of Materials with Laboratory Testing.
Theory of Structures and Structural Design.
Theory of Machines and Machine Design.
Heat Engines with Laboratory Testing.
Hydraulics with Laboratory Testing.
Students enrolled from September 19th to 22nd.
DAY TECHNICAL COLLEGE.
Full Time Courses in Mechanical, Civil, and Electrical Engineering for B.Sc. (Eng.), Degree, University of London, or College Diploma commence on September 25th. Entrance Examination commences September 19th. Fee: £18 per session. A higher fee will be charged to students not residing in London.
Full particulars of all Classes on application to the PRINCIPAL. W 187

## City of Cardiff Education COMMITTEE.

THE TECHNICAL COLLEGE.
Principal - CHARLES COLES, B.Sc. (Lond.).
DEPARTMENT OF ENGINEERING.
Head of Department:
A. W. LOVERIDGE, B.Sc. (Eng.), A.R.C.Sc.
SESSION 1922-23
(commencing on Tuesday, 3rd October, 1922).

The following COURSES have been arranged for Engineering Students:—
A Three-years' Course in Mechanical and Marine Engineering, jointly with the University College of South Wales and Monmouthshire.
A Two-years' Course for apprentices and others with facilities for practical experience in the Summer Term.
These Courses are suitable for students preparing for degrees in Engineering or for the examinations of the Engineering Societies.
Special Courses are also arranged for Marine Engineers preparing for the examinations of the Board of Trade.
For further particulars of Full-Time and Part-Time Courses, Entrance Examination, Scholarships, Fees, &c., apply to the Principal. Forms of application for admission to the Entrance Scholarship Examination, duly completed, must be received by the 18th September.
JOHN J. JACKSON, Director of Education, City Hall, Cardiff. W 66

ENGINEERING AND TECHNICAL OPTICS.

## Northampton Polytechnic INSTITUTE, St. John Street, London, E.C. 1.

ENGINEERING DAY COLLEGE.
Full-Time Day Courses in the Theory and Practice of Civil, Mechanical, and Electrical Engineering. The Courses in Civil and Mechanical Engineering include specialisation in Automobile and Aeronautical Engineering, and those in Electrical Engineering include specialisation in RADIO-TELEGRAPHY.
A SPECIAL ENTRANCE EXAMINATION is held at the end of September before the commencement of each session. The Courses include periods spent in commercial workshops and extend over four years. They also prepare for the Degree of B.Sc. in Engineering at the University of London. Fees £18 or £13 per annum.
THREE ENTRANCE SCHOLARSHIPS of the value of £62 each for the complete course will be offered for competition at the annual entrance examination in September.
OPTICAL ENGINEERING AND TECHNICAL OPTICS.
Full and Part-time Courses in this important department of Applied Science are given in specially equipped laboratories and lecture rooms. The annual entrance examination is held at the end of September.
EVENING TECHNICAL COURSES in all branches of Mechanical and Electrical Engineering commence on Monday, September 25th, 1922.

The Laboratories, both Mechanical and Electrical, are well equipped with modern apparatus which, on the Mechanical side, provides for specialisation in Automobile and Aeronautical Engineering, and, on the Electrical side, for specialisation in Alternate and Continuous Current Work, in Radio-Telegraphy and Telephony, and in Electrical Testing.
More complete particulars, together with conditions of entrance, &c., and all information respecting the work of the Institute can be obtained at the Institute or on application to—
R. MULLINEUX WALMSLEY, D.Sc.
Principal. W 222

## Correspondence Courses for

Inst. Civil Engrs., Inst. Mech. E., London Univ. (Matric., Inter., B.Sc.), and ALL ENGINEERING EXAMINATIONS personally conducted by MR. TREVOR W. PHILLIPS, B.Sc. (Honours), Assoc. M.Inst.C.E., M.R.S.I., F.R.S.A., &c. Also Day Tuition in Office. Excellent results at all Exams. Courses may commence at any time, and all Students receive individual tuition.—For full particulars apply to 3/11, TRAFFORD CHAMBERS, 58, SOUTH JOHN STREET, LIVERPOOL. 873

## Inst. C.E., I. Mech. E., B.Sc.,

and all Engineering Examinations.—Mr. G. P. KNOWLES, B.Sc., M.E.E., A.M.Inst.C.E., F.S.I., M.E.San.I., PREPARES CANDIDATES personally or by correspondence. Thousands of successes during the last sixteen years. Courses may commence at any time.—20, Victoria St., Westminster, S.W. Tel. 4780 Victoria. 854

## Inst. C.E. Exams.—Successes

as usual last Exam. by Correspondence Coaching. Successes by hundreds, several prizes. Sec. "O" embraces 28 years' professional experience. Address, 7434, Offices of ENGINEERING.

## Powering of Vessels.—A

Practical Course of Instruction by Correspondence.—Address, for particulars and terms, 748, Offices of ENGINEERING.

TENDERS.

THE HIGH COMMISSIONER FOR INDIA is prepared to receive

## Tenders for the Supply

of:—
1. TUBING, copper, solid drawn.
2. PINS, split, and screws for wood.
3. FILES.

Forms of Tender may be obtained from the Director-General, India Store Department, Branch No. 16, Belvedere Road, Lambeth, S.E. 1, and Tenders are to be delivered at that office not later than Two o'clock p.m. on Friday, the 29th September, 1922. W 201

T. RYAN,
Director-General.

METROPOLITAN BOROUGH OF WOOLWICH.

ELECTRICITY DEPARTMENT.

DISPOSAL OF ELECTRIC AND STEAM GENERATING PLANT AND OTHER ELECTRIC POWER STATION AUXILIARIES.

The Woolwich Borough Council invite

## Tenders for the Purchase of

STEAM ENGINES, DYNAMOS and ALTERNATORS, BOILERS, FEED PUMPS, BOBY WATER SOFTENER, FEED TANKS, AUXILIARY TANKS, WATER PUMPS, STEAM, FEED and WATER PIPING, and other auxiliary plant now available for disposal, in lots shown on schedules which may be obtained on application to the Borough Electrical Engineer, 44, Powis Street, Woolwich, S.E. 18.
The Tenders must be on Forms supplied, and in strict accordance with the conditions stated.
The Council reserve the right to withhold any lot from sale and to accept any Tender.
Tenders to be sealed and endorsed "Tender for Purchase of Plant," and delivered to me at the Town Hall, Wellington Street, Woolwich, not later than Five p.m., on Tuesday, the 19th September, 1922.

By Order,
ARTHUR B. BRYCESON,
Town Clerk.
W 235

THE BURMA RAILWAYS COMPANY, LIMITED.

The Board of Directors of the Burma Railways Company, Limited are prepared to receive

## Tenders for the Supply

of:—
200 lengths (6 ft.) of GALVANISED RIDGING, and
120 tons of GALVANISED CORRUGATED SHEETS.
For each copy of the Specification a fee of 10s. will be charged, which fee is not returnable.
Tenders enclosed in sealed envelopes endorsed "Tender for Galvanised Steel or Ironwork," must be delivered at the Company's Offices not later than Twelve Noon on Friday, 15th September, 1922. The Directors do not bind themselves to accept any or the lowest Tender, and reserve the right to divide the order.

By order of the Board,
F. C. FRANKS,
Secretary.
199, Gresham House,
Old Broad Street,
London, E.C. 2.
6th September, 1922. W 217

GREAT SOUTHERN & WESTERN RAILWAY (IRELAND).
CONTRACTS 1922.
The Directors of the Great Southern and Western Railway Company are prepared to receive

## Tenders for the Supply of the

undermentioned STORES for Three Months commencing 1st October, 1922.

| | No. of Form. | | No. of Form. |
|---|---|---|---|
| Acid, Sulphuric ... | 3D | Glass and China Sundries ... ... | 27B |
| Asbestos Sheeting, etc. ... ... ... | 40 | Hardware (Sundry) | 17 |
| Baskets ... ... | 10 | India Rubber Goods | 9A |
| Bolts, Nuts and Rivets | 15 | Implements, Sundry | 21 |
| Brooms and Brushes | 13 | Iron Tubes and Fittings ... ... | 39 |
| Brass Fittings for Carriages... ... | 18 | Leather ... ... | 12 |
| Do. do. for Water | 36A | Locks and Keys ... | 19 |
| Do. do. for Gas ... | 36B | Mats, Fibre ... ... | 10 |
| Canvas and Sacks ... | 6 | Nails ... ... ... | 31 |
| Castings, Mall. Iron | 11 | Packings ... ... | 40 |
| Coach Screws and Washers ... ... | 15 | Plumbago ... ... | 41 |
| Colours ... ... ... | 3 | Rain Water Pipes and Gutters ... ... | 25 |
| Corks ... ... ... | 39 | Ropes, Twine, & Flax | 4 |
| Crucibles ... ... | 41 | Sewer Pipes, Plaster, etc. ... ... ... | 33 |
| Drysalteries ... ... | 3 | Soaps ... ... ... | 8C |
| Emery and Glass Cloth, etc. ... ... | 28 | Sponge Cloths ... | 5 |
| Files and Tool Steel | 20 | Signal Wire Pulleys | 11 |
| Fire Bricks and Clay | 33 | Screws and Split Pins | 14 |
| Foundry Requisites | 42 | Shovels, Spades, etc. | 21A |
| Galvanized Sheets, Buckets, etc. ... | 23 | Tin Plates ... ... | 29 |
| Grates, Stoves and Fenders ... ... | 24 | Waste ... ... ... | 8A |
| Grindstones ... ... | 26 | Wicks ... ... ... | 5 |
| Glass, Sheet, and Plate ... ... | 27A | Wire, Fence and Signal ... ... | 30A |
| | | Wirework ... ... | 30B |

Forms of Tender can be obtained on PAYMENT of 1s. each from the STORES SUPERINTENDENT, GENERAL STORES DEPARTMENT, G.S. & W.R., INCHICORE, DUBLIN. Applications for forms by Post must be accompanied by Postal Order. Stamps cannot be accepted. All enquiries for information should be also directed to the Stores Superintendent.
Patterns may be inspected at the General Stores Department on and after the 8th inst., between the hours of Ten a.m. and Four p.m. (except on Saturdays).
Tenders must be enclosed in the special envelope supplied for the purpose with each schedule, and must be posted so as to be with the undersigned before Ten a.m. on Wednesday, 20th September, 1922.
The Directors will not consider any Tender unless it is furnished on the Company's Form, and do not bind themselves to accept the lowest or any Tender.
By Order,
ROBERT CRAWFORD, Secretary.
Kingsbridge Terminus, Dublin,
September, 1922. W 198

NEW SOUTH WALES GOVERNMENT.

MINISTER OF PUBLIC WORKS.

## Tenders are Invited for

the MANUFACTURE, SUPPLY and ERECTION of TWO WATER TURBINES and GENERATORS required in connection with Barren Jack Hydro-Electric Development.
Specification and Drawings can be seen and copied at the Office of the Consulting Engineer, 64, Victoria Street, London, S.W. 1, or at the Office of the undersigned.
Tenders must be delivered not later than Eleven a.m. on Monday, 23rd October, 1922, in sealed envelopes, addressed to:—
THE AGENT-GENERAL
FOR NEW SOUTH WALES,
Australia House,
Strand, London, W.C. 2.
6th September, 1922. W 234

STATE ELECTRICITY COMMISSION OF VICTORIA.

TENDERS FOR PLANT.

## Tenders are Hereby In-

vited for the SUPPLY, DELIVERY, etc., of the following for the Morwell Power Scheme.
Copies of Tender Form and Specification will be available upon application to:—
AGENT-GENERAL FOR VICTORIA,
Melbourne Place,
Strand,
London, W.C. 2.
SPECIFICATION No. 282—COAL HANDLING PLANT FOR MORWELL POWER STATION AND BRIQUETTING WORKS.
CHARGE:—
£2 2s. for the first two copies of Tender Form, Conditions of Contract, Specification and Drawings complete. These charges will be returned on receipt of a *bona fide* Tender. A third copy and any further copies will be supplied for the sum of £1 1s. each.
PRELIMINARY DEPOSIT.
A Preliminary Deposit of £50 is to be lodged with Tender.
The Specifications may be inspected at the above-mentioned office.
The Commission does not bind itself to accept the lowest or any Tender.
Tenders on prescribed form, properly endorsed and addressed, must be delivered to the undersigned in Melbourne not later than Five p.m., 18th December, 1922.

R. LIDDELOW,
Secretary.
State Electricity Commission of Victoria,
Melbourne,
Victoria,
Australia. W 96

THE SOUTH INDIAN RAILWAY COMPANY, LIMITED, are prepared to receive

## Tenders for the Supply of:—

1. 704 AXLEBOXES for Wagons.
2. 36,000 FOG SIGNALS.
3. RIVETS, NUTS AND PINS.
4. DRYSALTERIES.

Specifications and Forms of Tender will be available on Wednesday, the 13th September, 1922, at the Company's Offices, 91, Petty France, Westminster, S.W. 1.
Tenders addressed to the Chairman and Directors of the South Indian Railway Company, Limited, marked:—"Tender for Axleboxes," or as the case may be, must be left with the undersigned not later than Twelve noon on Wednesday, the 4th October, 1922.
The Directors do not bind themselves to accept the lowest or any Tender.
A charge, which will not be returned, will be made of 10s. for each copy of Specifications Nos. 1, 2, 3 and 4.
Copies of the Drawings may be obtained at the Office of Messrs. Robert WHITE & PARTNERS, Consulting Engineers to the Company, 3, Victoria Street, Westminster, S.W. 1.

A. MUIRHEAD,
Managing Director.
91, Petty France, S.W. 1.
6th September, 1922. W 251

APPOINTMENTS OPEN.

COUNTY BOROUGH OF CROYDON.
EDUCATION COMMITTEE.
Central Polytechnic.—Mechanical Engineering Department.

## Required for the Winter

Session, 1922-23, a TEACHER of MACHINE CONSTRUCTION (advanced) for one evening per week (Friday). Salary 21s. per evening of two teaching hours. Applications, giving particulars of education, training, experience, present appointment, &c., should reach the undersigned not later than 18th September, 1922.

JAMES SMITH,
Clerk to the Committee.
Education Office,
Katharine Street,
Croydon. W 151

## Wanted, a Qualified Technical

ASSISTANT with initiative for the Patent Department of a large engineering firm. Must have electrical and mechanical knowledge, and a working knowledge of practice in patent law, and in obtaining patents. Experience in office routine important.—Write, BOX No. 1178, c/o S. DAVIS & Co., 30 & 31, St. Swithin's Lane, London, E.C. W 197

## Wanted, General Manager

for a new wet process cement plant in India now in operation, must also be a capable chemist.—State age, experience, and salary required to MAXTED & KNOTT, LTD., Consulting and Cement Works Engineers, Burnett Avenue, Hull. W 139

## Bolckow, Vaughan & Co.,

Limited, invite APPLICATIONS for the POST of COMMERCIAL MANAGER; only first-class men with Iron and Steel trade experience will be considered. All applications will be treated in the strictest confidence.—Communications marked "Private and Confidential" to be sent to G. GOODYSMITH, Esq., C.B.E., c/o BOLCKOW, VAUGHAN & Co., Limited, Middlesbrough. W 204

# THE FRICTIONAL COEFFICIENT OF CONCRETE SURFACES IN PIPES AND CHANNELS.

By E. PARRY, B.Sc., M.INST.C.E.

EVER since Stanton* demonstrated conclusively that the hypothesis upon which was based the principle of dynamic similarity was substantially sound for, at any rate, a wide range of conditions, the principle has been extensively applied in aeronautics, and to a lesser extent in the practice of steam turbine design, but in regard to hydraulics its application has been limited almost entirely to the laboratory, and so far it has not received the recognition of hydraulic engineers in general. This is evidenced by the fact that quite recent publications of tests and experiments do not contain a reference to it, whilst all the old empirical formulæ are paraded for comparison with the inevitable "author's formula" and conclude with a table of the indices and coefficients appertaining to the various formulæ given.

According to the principle above enunciated it is asserted that the following relation should hold good, viz. :—

$$\frac{R}{\rho v^2} = \psi\left(\frac{v d}{\nu}\right)$$

Where R is the frictional force per unit area in absolute units, $\rho$ is the density of the fluid, $v$ the velocity of the fluid, $d$ the diameter of the pipe and $\nu$ the kinematic viscosity or the ratio of the viscosity $\mu$ of a fluid to its density $\rho$, and $\phi$ stands for "function of."

The expression $\frac{R}{\rho v^2}$ may be shown to be equivalent to $\frac{r s g}{v^2}$, where $g$ is the gravitational constant, $r$ is the hydraulic mean depth, and $s$ the hydraulic gradient, a form which is more usual in the practice of hydraulics, consequently we may say that $\frac{r s g}{v^2}$ is a function of $\frac{v d}{\nu}$, also that $\frac{r s}{v^2}$ is a function of $\frac{v d}{\nu}$ or of $\frac{v p}{\nu}$, where $p$ is the wetted perimeter, a form which is convenient for non-circular conduits, also for conduits not running full and for channels.

In a recent article† attention was called to the advantages of applying this principle to co-ordinate experimental data, it was pointed out that this operation enabled all the observations on fluid friction, whether liquid or gaseous, to be correlated, subject to the limitation that the roughness of the surface must be proportional to some dimensions such as the diameter of a pipe, in order that the value of $\frac{r s}{v^2}$ should be the same for the same value of $\frac{v d}{\nu}$ or $\frac{v p}{\nu}$. The futility of field experiments for the purpose of determining pure surface characteristics was emphasised, and the opinion expressed that tank experiments were more likely to yield consistent results.

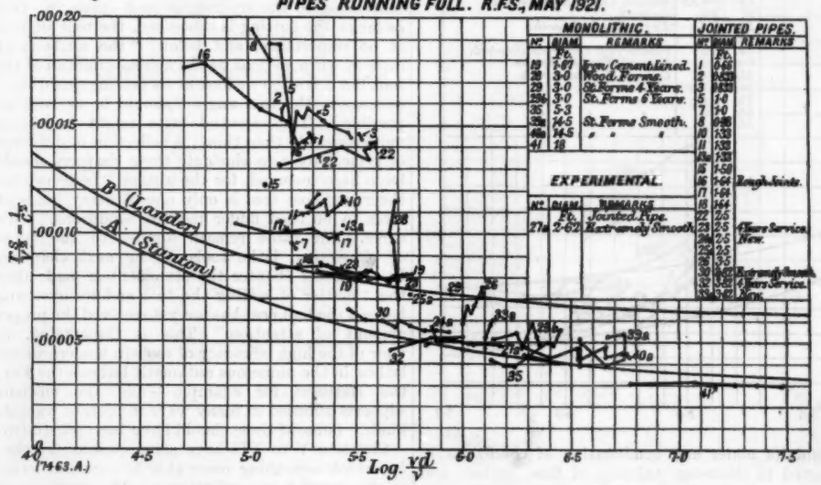
Although precise results can only be obtained in the manner specified, some useful conclusions may be arrived at by the study of the results of field experiments when co-ordinated in the manner mentioned and quite reliable data obtained for future guidance.

An opportunity of effecting a study of the frictional characteristics of concrete surfaces, and also of the loss of head due to joints and other inequalities, has presented itself by the publication by the Bureau of Agriculture,* U.S.A., of a bulletin summarising the results of experiments made by that department and other authorities upon the flow of water in concrete pipes, tunnels and channels, together with some brick-lined tunnels. This is a most important contribution to the subject, embodying as it does all tests made to date on concrete surfaces in the form of pipes and channels, with a specification of the nature of the surface.

The series of experiments upon the concrete pipes running under pressure comprise 41 pipes with a diameter varying from 0·67 ft. to 18 ft.

Three types of pipe are included, viz. :—

*Fig. 1.* FRICTION IN CONCRETE PIPES. PIPES RUNNING FULL. R.F.S., MAY 1921.




(1) Pipe made in lengths and jointed, and either made by the dry mix process and cement washed or by the wet mix process on oiled forms and uncoated.

(2) Tunnels lined with concrete in which either timber or iron forms have been used.

(3) Cement-lined metal pipes.

Some of the surfaces have been treated by being washed with cement mortar or grouted with cement, while others have been left with the marks of the forms, and in the case of pipes made in lengths the joints have in some instances been carefully smoothed over.

It will be seen from the above that the experiments cover a large variety of conditions in regard to surface, diameter of pipe and velocity of flow. Unfortunately, however, the temperature of the water was not observed and in the present paper the temperature throughout has for the purpose of comparison been assumed to be 60 deg. F.

The observations on pipes running full are tabulated and plotted in Fig. 1 hereto, where the values of $\frac{r s}{v^2}$ are plotted against the value of log $\frac{v d}{\nu}$. On the same sheet are two curves which are employed as data for reference. One is drawn through a series of observations on smooth brass pipes by Stanton, and marked A, and the other by Lander on drawn steel pipe and marked B, which have been dealt with more specifically in the previous article referred to above.

The experiments recorded in the United States Department of Agriculture Bulletin are plotted on the same sheet, and on regarding the result the inaccuracy of tests carried out on pipes and channels under field conditions will be readily realised.

The futility will also be realised of attempting to correlate or co-ordinate experimental results without a theoretical basis.

As an example of the unreliable character of some of the tests we may cite experiment No. 28, where the value of $\frac{1}{C^2}$ varies over 80 per cent. for approximately the same value of $\frac{v d}{\nu}$. Another example is No. 35, which has a general slope in the wrong direction, whilst in all cases although the general trend is in accordance with the law which is exemplified in Stanton and Lander's experimennt the individual observations are erratic.

However, the cumulative effect of the experiments is such as to enable fairly conclusive deductions to be made in regard to the frictional head in concrete pipes.

First with respect to jointed pipes. Series 16, 27A and 30 afford a clue to the interpretation of the results; the first, No. 16, is noted for its rough joints and its position on the diagram amongst a group of others enables us to say that the whole of the pipes in this group, viz., 1, 2, 3, 5, 8, 16, 22, suffer from rough joints, and that the differences in the surface characteristics, some of which are remarkably smooth, are entirely masked by the joints. With regard to No. 27A and No. 30, special care was taken to make a smooth joint, with the result that these pipes, which are 24½ in. and 42 in. diameter respectively, compare favourably with smooth brass pipes of from 0·144 in. to 4·96 in. diameter experimented on by Stanton, represented by Curve A, and are geometrically similar or nearly enough so for practical purposes, *i.e.*, their roughness or irregularities are generally in proportion to the respective diameters of the brass pipe and the concrete pipes. Other pipes, such as No. 10 and No. 17, &c., indicate that the joints intervene to impede the flow, but that they are not so rough as those of the group surrounding No. 16.

Experiment No. 19 discloses an interesting result. This pipe is composed of a wrought iron casing lined with cement, 20 in. internal diameter, and is presumably made in long lengths, at any rate the joints are not much in evidence, and the reason why No. 19 is not in the same class as Nos. 30 and 27A is due probably to surface irregularities or growths; as it is it belongs to the same category as Curve B.

On comparing the group represented by rough joints with the group represented by smoothed joints, it is evident that the latter belong to the same order of curves as A and B, whilst the former belong to a different order altogether. We may conjecture that the total head lost in the former case has two components, one due to surface friction and the other a summation of all the heads lost at the individual joints, each component in turn containing an appropriate viscosity term; or we may adopt the conclusion arrived at by Schiller* who finds that for "the occurrence of turbulence one rough place is sufficient and that persistent turbulence does not require a continuance rough boundary. The place causing the greatest disturbance is therefore the only one which comes into account and determines the critical number. According to this conclusion it only requires a rough joint at very rare intervals to give the effect of continuous roughness, and moreover the initial condition of the water entering the pipe has a marked influence upon the condition of flow in the pipe, which may also account for some of the discrepancies noticed in the observations.

On regarding the jointed pipes as a whole it is evident that for values of log. $\frac{v d}{\nu} = 5{\cdot}5$, that is of $v d = 3{\cdot}8$; if they are to be laid under conditions where the smoothness of the joints cannot be assured, then the value of $\frac{1}{C^2}$ cannot be safely taken at less than 0·00015, *i.e.*, C in Chezy's formula cannot be more than 82·8. On the other hand, if care be

* T. E. Stanton and J. R. Pannell, "Similarity of Motion in Relation to the Surface Friction of Fluids." N.P.L., Collected Researches, vol. xi, 1914.

† E. Parry "On a Theory of Fluid Friction and its Application to Hydraulics," E.E. Journal, October 1920, page 146.

* F. C. Scobey, "The Flow of Water in Concrete Pipes," U.S. Dept. of Agriculture, Bulletin No. 852.

* L. Schiller, *Zeits. f. Physik*, 3, 5, pages 412 to 416, 1920, see Science Abs. No. 763, vol. xxiv, Part V, No. 281.

taken with the joints a pipe of the same diameter may have a value of $\frac{1}{C^2}$ as low as 0·00006, corresponding to a value of C = 129, or 50 per cent. higher than the previous value. Any other values of $v\,d$ which may be outside the range of present experimental data may be compared by drawing curves by freehand through the observations and projecting the curves in either direction as may be required provided that the curves are not extended too far.

Referring next to the monolithic pipes, these vary considerably in degree of smoothness; those cast on timber forms bear the impress of the longitudinal joints and also circumferential joints due to lack of good alignment in moving the forms; again those cast on steel forms bear the impress of joints and rivets and the alignment may be imperfect, which impedes the flow in two ways, i.e., by forming shoulders at the joints and by a slight change in the direction of flow. On the other hand, such pipes or conduits made by this method are invariably of large diameters, and large surface irregularities have not the same effect as on pipes of smaller diameter, and in consequence the readings are more consistent and more in accord with curves A and B, which represent surface characteristics only, unaffected by joints or other disturbing factors.

Referring again to Fig. 1, experiments Nos. 39A and 40A are upon pipes 14·5 ft. in diameter, and although the observed values are irregular the general trend is in accordance with basic principles and indicates that for values of $\log \frac{v\,d}{\nu} = 6{\cdot}5$, i.e., for $v\,d = 38$ a value of $\frac{1}{C^2} = 0{\cdot}00004$ may be predicted, corresponding to a value of C = 158 in Chezy's formula.

As regards series No. 41, this represents results of experiments upon flow of water in conduit No. 2 of the Ontario Power Company, the diameter being approximately 18 ft., and inasmuch as very high velocities were used, large values of $v \times d$ were obtained; further special care was taken to remove irregularities, with the result that very low values of $\frac{1}{C^2}$ were obtained which are located in the asymptotic region of the curve, where the value of $\frac{1}{C^2}$ and consequently the value of C tends towards constancy. The values plotted are not the original observations but derived values computed by the engineers of the Power Company. It would have been more satisfactory to deal with the original values, but these are not recorded in the bulletin.

The next series relates to pipes not running full, the values being plotted on Fig. 2, the values of $\frac{r\,s}{v^2}$ against $\log \frac{v\,p}{\nu}$, where $p$ is the wetted perimeter. There are also tabulated on the same sheet the particulars relating to diameter and nature of the surface.

On considering the results it will be obvious at once that the general trend is different from that of smooth pipes running full, which conform generally to the form of the curves marked A and B; in other words, the characteristic curves of open pipes and channels differ from closed pipes running full and evidently contain one or more additional terms involving velocity.

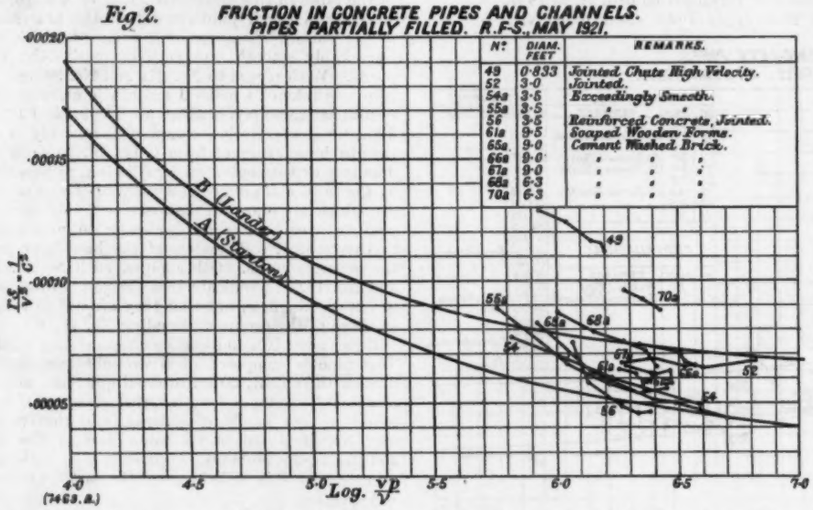
Referring to the individual pipes, No. 49 is a jointed pipe, and we may conclude from the evidence afforded in Fig. 1 that its position on the chart is due to rough joints. The other jointed pipes, viz., No. 52 and No. 56, are better situated, and we may conclude that the joints are fairly smooth. No. 54A and No. 55A are recorded as being exceedingly smooth, which is borne out by the location of the graph. Nos. 65A, 66A, 67A, 68A and 70A are brick lined, and it is evident that No. 70A is considerably rougher in finish than the others.

In conclusion it may be stated that experimental data recorded in the bulletin, covering as they do the whole range of engineering practice in concrete pipes, when co-ordinated by means of the function $\frac{v\,d}{\nu}$, affords such information as will enable the engineer to predetermine with considerable confidence the frictional loss in concrete pipes and conduits under any combination of conditions in regard to diameter, velocity of flow, surface and jointing.

For the information of those desiring to employ this method it may be stated that the previous article on this subject already referred to contains tables of the values $\log \frac{v\,l}{\nu}$ for different values of temperature and of $v\,l$, where $l$ is any characteristic dimension such as the diameter or periphery of a pipe running full or the wetted perimeter of a pipe not running full or of a channel.

In all field experiments care should be taken to observe the temperature of the water, also the amount of matter in suspension and the degree of aeration, all of which have some influence upon the results. The observer should also have regard to the state of the water at entry and to the presence of occasional rough spots on the pipes as these have an influence upon the results.

*Fig. 2.* FRICTION IN CONCRETE PIPES AND CHANNELS. PIPES PARTIALLY FILLED. R.F.S., MAY 1921.




On page 11 of wood-workers' chisels show angles about twice as large as they are actually. And a keen chisel-cutting "plankway" as the drawings show does not split off chips but shavings. It will be tantalising to the student to read—page 26—that as far as the cutting is concerned, the tool angle is of no importance, and below, "the angle is of interest when we look at the lasting qualities of the tool, but not when we look at its cutting qualities;" and again, the tool angle "should be as large as possible." The essential facts might be stated more concisely than this. A collection of drawings of typical tools to elucidate these chapters should have been included, for the author "believes that the round-nose tool is only one of many kinds of tools to be used under modern conditions." We agree. The same remark applies to the types of planer and lathe tools in the next chapters. In the latter chapter the statement is made that the "matter of setting the tool and its overhang beyond the tool post has not yet received the proper amount of attention." This is disparaging, in view of the high efficiency of tools in modern turret lathes, in the numerous automatic lathes—the Fay, the Hartness for example—and the efficient supports afforded in many ways to tools of various kinds. Some of these should have been illustrated.

Chapters V to VII have some curious sketches for which something more akin to common forms might have been substituted. The method of drilling tapered holes shown, page 100, would push the drill away at the second setting. Such holes would be roughed with a stepped drill, and finished with a tapered reamer. Chapter VIII, on Milling Cutters, discusses rather tediously the reason for cutter marks, and chatter, the thickness of chips, the hypothetical case of a cutter having only one tooth, fluctuations in torsion, and the case of spiral cutters, and elimination of chatter. The admission is made that the treatment is only a "working hypothesis." But time and space might have been better occupied with summaries of known facts. Selections of standard cutters, dimensioned, are given in Chapters IX and X. On page 139 the statement is made that the spindle of a vertical milling machine is never at perfect right angles to the work. On page 143 the use of a tang for driving end mills is discouraged on the ground that the intimate contact between the shank of the mill and the taper of the spindle may be destroyed. This is a matter of cleanliness of surface, and the presence of grit would produce inaccuracy though a screw were used. Chapter XI deals with cutter sharpening, and the alternative of cup or of disc wheels is discussed, illustrated with a few diagrams, but without examples from practice. Chapter XII treats of form tools, Chapter XIII of shear tools, and the boring of holes with shear tools is advocated. The use of liquids for lubrication, and the carrying off of heat occupies Chapter XIV. A theoretical tool having 90 deg. contained angle is made the occasion of nearly a page of trigonometrical formulæ to demonstrate that in reality chips do not split

## LITERATURE.

*Metal Cutting Tools: Their Principles, Action and Construction.* By A. L. DE LEEUW, M.S., M.E. New York and London: McGraw-Hill Book Company, Inc. [Price 15s. net.]

THIS is a reprint from the *American Machinist*, written for "the young engineer, the student, the foreman, the time-setter and the ambitious mechanic." But we think that the author approaches, and deals with his subject from an undesirable view-point. He assumes that "Very few observations and experiments as to the real nature of the cutting action of tools have been made." And so, instead of treating the subject on a basis of "well-established and incontrovertible facts" he adopts a working hypothesis of his own. Yet everyone knows that the researches on tool formation and action have been very numerous and minute, not only made by societies and institutions, but also by manufacturing firms both in England and America, who have freely given the results of their experiments to the users of tools. No writer familiar with the subject can now avoid assimilating consciously or unconsciously the general conclusions that are based on these researches. But throughout the book these are almost ignored, and instead, hypothetical cases are stated and drawings are given, a large proportion of which do not correctly represent tools in actual service.

Chapter I, the Formation of Chips, refers the action of all cutting tools to that of the knife, rather unnecessarily laboured, and that of the wedge, and many needless diagrams are given, the space occupied by which could be better used for illustrating tools in actual service. The statement on page 9 that every metal-cutting tool viewed under a sufficiently strong magnifying glass shows a rounded edge is puerile. So would a needle. Yet one has to be careful when handling newly-sharpened milling cutters. The drawings on

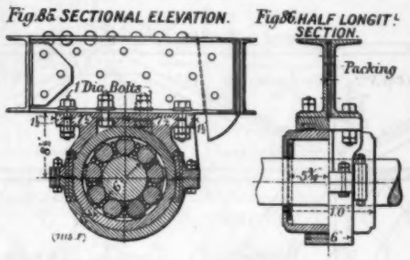
off at an angle of 45 deg. Chapter XV on generating tools describes the Gleason cutter for bevel gears, and that for spiral bevels, the Fellows cutter, for spur, and for helical gears, the hob, and the minute flats which it produces. Thread-cutting tools with illustrations are treated in Chapter XVI, and taps, dies and chasers. Hollow mills and special tools occupy Chapters XVII and XVIII. An index concludes a volume of 328 pages with 306 illustrations.

## RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.

By P. J. RISDON.

(*Continued from page* 228.)

*Transporter Car.*—The loading platform of the car measures 41 ft. in length by 26 ft. 3 in. in width. The total maximum working load is 100 tons, although this is not often reached in practice. The car and its details are illustrated in Figs. 52 to 80, on Plate XXV, and Figs. 81 to 108 on the present page and pages 288 and 289. The general arrangement of the car and suspension is shown in Figs. 52 and 53. The clear width of roadway is 20 ft.; the footwalk on one side is 4 ft. $9\frac{7}{64}$ in. wide and on the other 1 ft. $4\frac{15}{64}$ in. One tramway track of 4 ft. $8\frac{1}{2}$ in. gauge is laid on one side of the roadway, and provision is made for another track. A good idea of the car and method of suspension will be obtained from the photographs reproduced in Figs. 1 and 2, pages 193 and 194, *ante*.



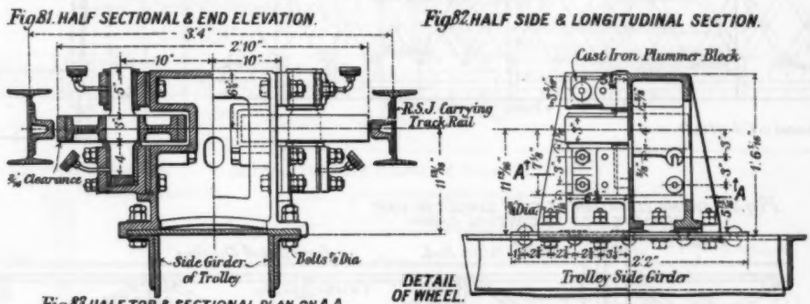



Fig.81. HALF SECTIONAL & END ELEVATION.
Fig.82. HALF SIDE & LONGITUDINAL SECTION.
Cast Iron Plummer Block
R.S.J. Carrying Track Rail
Side Girder of Trolley
Bolts Dia.
Trolley Side Girder

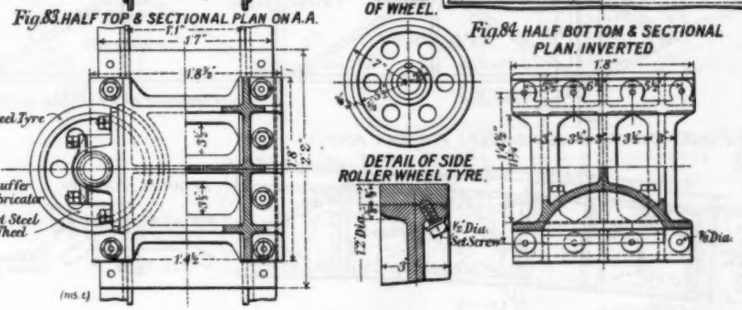


Fig.83. HALF TOP & SECTIONAL PLAN ON A.A.
DETAIL OF WHEEL.
Fig.84. HALF BOTTOM & SECTIONAL PLAN. INVERTED
Steel Tyre
Stauffer Lubricator
Cast Steel Wheel
DETAIL OF SIDE ROLLER WHEEL TYRE.

The suspension frame and trolleys are illustrated in Figs. 52 to 86, Plate XXV and the present page, while a view of the car, and details of this part of the work, are given in Figs. 87 to 95 on the present page and Figs. 96 to 108 on pages 288 and 289.

Dealing first with the overhead trolley this, as shown in Figs. 53 and 68, will be seen to comprise four sets of 8-wheeled bogies, from which depends the main trolley frame upon which the suspension frame hangs, the car being attached to the latter. The trolley frame shown in Figs. 74 to 76, &c., comprises a pair of longitudinal double webbed girders, 57 ft. $10\frac{3}{4}$ in. long overall. The webs, which are spaced 13 in. apart, are of $\frac{1}{2}$ in. plate section of varying depth, except for the centre portion where, for a length of 20 ft. 6 in., angle-web bracing is substituted and the depth of the girders is reduced to 2 ft. 3 in. to allow flexibility between the bogie centres. The flanges consist of 6-in. by 3-in. by $\frac{1}{2}$-in. angles laced together horizontally, Fig. 76. Below the bogies, which are shown in Figs. 74 and 77, the girders are increased in depth to 5 ft. 2 in., and 6 in. diameter pins connect the webs to the suspension frame dealt with below.

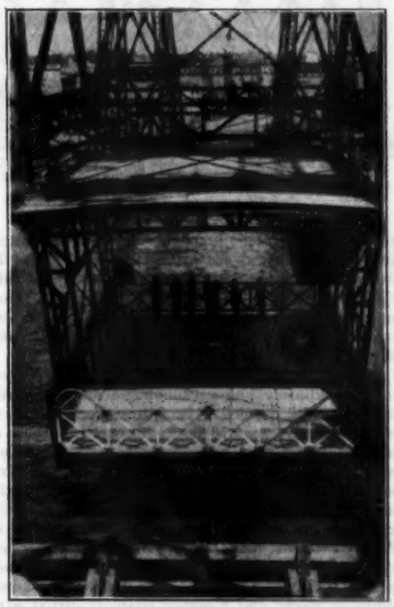


FIG. 87.

On each side of each pin, vertically beneath the centre of each pair of bogie wheels, is a pair of hanger links, $7\frac{1}{2}$ in. by $\frac{3}{4}$ in. by 3 ft. $1\frac{1}{4}$ in. long, centre to centre of pins with 4 in. pin connections at the lower ends, by which the trolley frame is suspended from the bogie trucks, thus distributing the weight equally upon the trolley wheels. Internal plate web diaphragms stiffen the girder webs at suitable

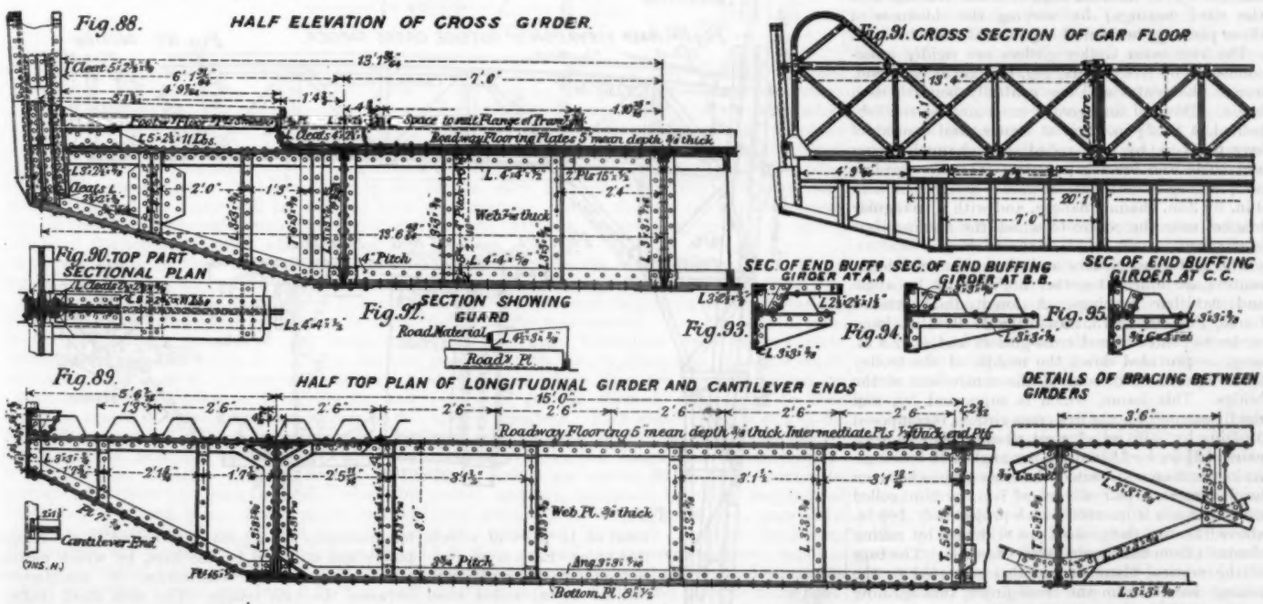


Fig.88. HALF ELEVATION OF CROSS GIRDER.
Fig.91. CROSS SECTION OF CAR FLOOR
Fig.90. TOP PART SECTIONAL PLAN
Fig.92. SECTION SHOWING GUARD
Fig.93.
Fig.94.
Fig.95.
SEC. OF END BUFFS GIRDER AT A.A
SEC. OF END BUFFING GIRDER AT B.B.
SEC. OF END BUFFING GIRDER AT C.C.
Fig.89. HALF TOP PLAN OF LONGITUDINAL GIRDER AND CANTILEVER ENDS
DETAILS OF BRACING BETWEEN GIRDERS
Roadway Flooring 5" mean depth, ¾" thick. Intermediate Pls ½" thick, end Pls
Cantilever End.
Web Pl. ⅜" thick
Bottom Pl. 6½"

# DETAILS OF THE RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.

Fig. 96. HALF ELEVATION OF CAR SIDE GIRDER.

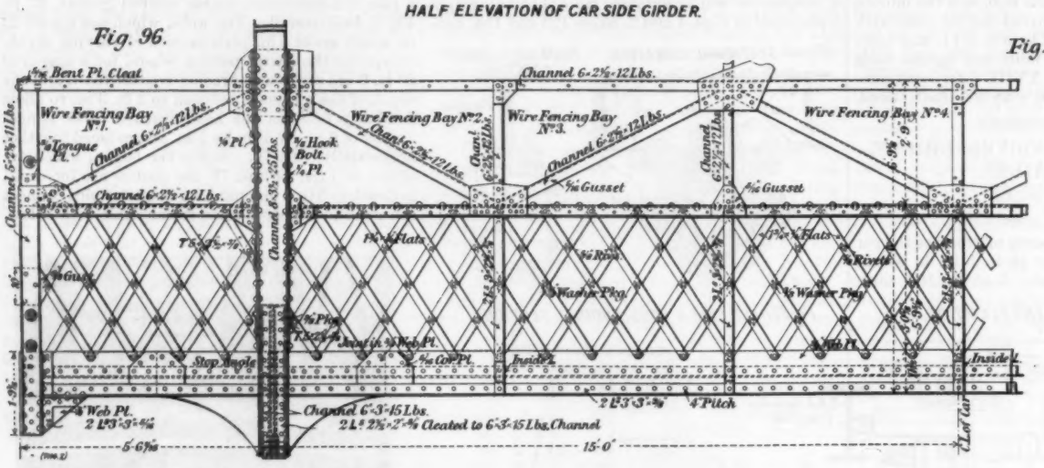
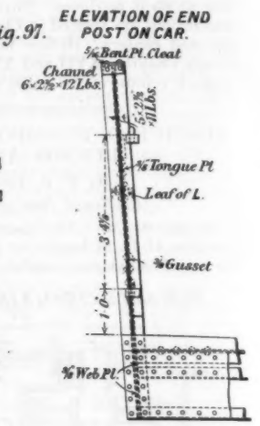



Fig. 97. ELEVATION OF END POST ON CAR.




intervals. The bogie brackets, to which the hanger link pins are secured, are not rigidly connected to the trolley girders, but horizontal and raking tie rods, 1½ in. diameter, with turnbuckles for adjustment, are provided, as shown in Fig. 74, &c., to prevent longitudinal swaying of the suspension frame about the hanger link pins.

Mounted upon the top of the main trolley girders and immediately below each bogie are three cast steel brackets, spaced 7 ft. 6 in. apart, centre to centre (Figs. 74 and 76) each supporting a pair of horizontal cast-steel rollers which take the transverse wind thrust, a space of $\frac{1}{8}$ in. being allowed between the roller treads and the heads of the horizontal bridge rails riveted to the webs of the track rail joints. Details of these are given in Figs. 81 to 84, page 287. The roller axles are 3½ in. diameter, with 2½-in. diameter journals carried in bronze bushed bearings and cast-iron plummer blocks and footstep bearings, fitted with Stauffer lubricators. Packings of ¼ in. nominal thickness were inserted betweeen the bearings and the steel castings; by varying the thickness of these packings horizontal adjustment was obtained.

The two main trolley girders are rigidly cross-connected by five girders, Fig. 68, one at each end, one at the centre and one centrally beneath each bogie. The end and centre cross-girders are fish-bellied, 4 ft. 2⅛ in. deep at centre, and consist of inverted 7-in. by 3-in. rolled steel channel flanges and angle web bracing in pairs. The cross-girders between bogie centres are of similar design, but with 9-in. by 3-in. channel flanges, and with a triangular bracket near the centre to which the hauling rope is attached.

The end cross-girders and those between bogie centres are braced together horizontally by angle and flat bar bracings. A longitudinal trussed frame, Figs. 69 to 73, measuring 57 ft. 3 in. long, centre to centre of end cross-girders and 4 ft. 3 in. deep, is provided down the middle of the trolley frame spaced 8¾ in. out of the centre line of the bridge. This frame, which is supported by, and rigidly secured to, the five cross-girders, is composed of 7-in. by 3-in rolled steel channel flanges with pairs of 2½-in. by 2½-in. by ⅜-in. angle-web bracings. At its junction with each of the cross-girders between bogie centres, a pair of vertical 7-in. by 3-in. rolled steel channels is inserted which project 2 ft. 10¾ in. above the top flange and are stiffened by raking channels from the upper flange channels. The tops of the vertical channels are also gussetted to the raking channel from the cross-girder, thus forming a very rigid bracket on which a draw-bar spring is mounted to which the steel wire hauling rope is secured (Figs. 69, 72 and 73). Horizontal diagonal bracing between the centres of the main trolley girders and the centres of the bogie cross-girders render the trolley frame perfectly rigid horizontally.

Each of the four sets of trolley bogies (Fig. 68) comprises a pair of four-wheel trucks, making a total of 16 pairs of wheels and axles. Each truck consists of two pairs of longitudinal 10-in. rolled steel channels, as shown in Figs. 74, 77 and 78, from which the ½-in. suspender plates depend to which the trolley hanger links are connected. The pairs of channels are braced together by internal channel diaphragms and a top horizontal flange plate, ¼ in. thick. The two trucks are connected longitudinally by a ½-in. plate bolted to the flange plates and stiffened by tee bars, by which means a vertically-flexible connection is maintained between the two trucks. The cast steel trolley wheels, Fig. 77, are 2 ft. 6 in. diameter, on tread, with steel tyres shrunk on. The axles are of forged steel, 6 in. diameter, and run in oil bath roller bearings, two bearings to each pair of wheels and axles being provided centrally, beneath the truck channel girders. These are shown in Figs. 85 and 86, page 287.

The suspension frame is of the rigid trussed type

Fig. 98. FRONT ELEVATION OF SIDE GIRDER OF CAR OPPOSITE SIDE TO CONTROL CABIN.

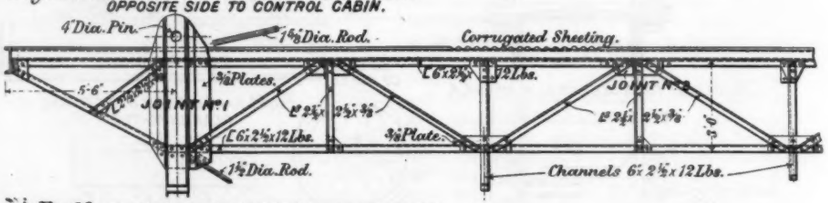



Fig. 99. CENTRE CROSS GIRDERS FOR CAR ROOF.

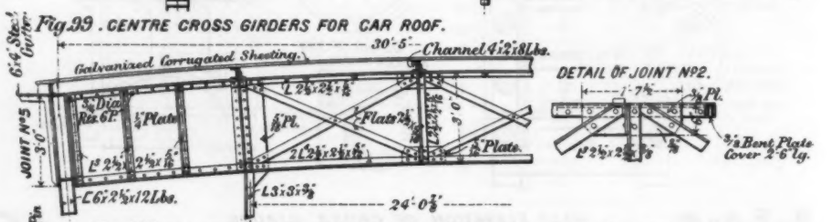



Fig. 100. HALF ELEVATION OF OUTSIDE CROSS GIRDER.

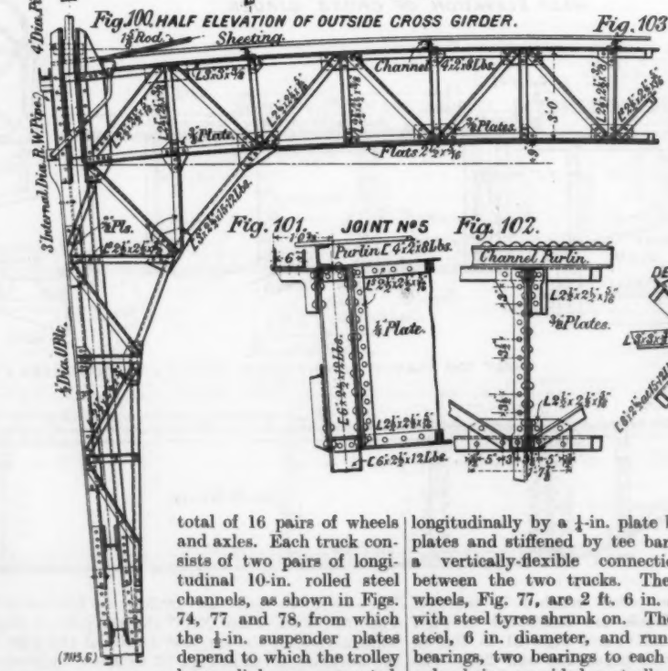



Fig. 101. JOINT No. 5

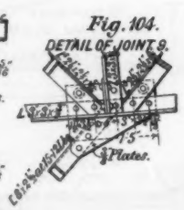



Fig. 102.

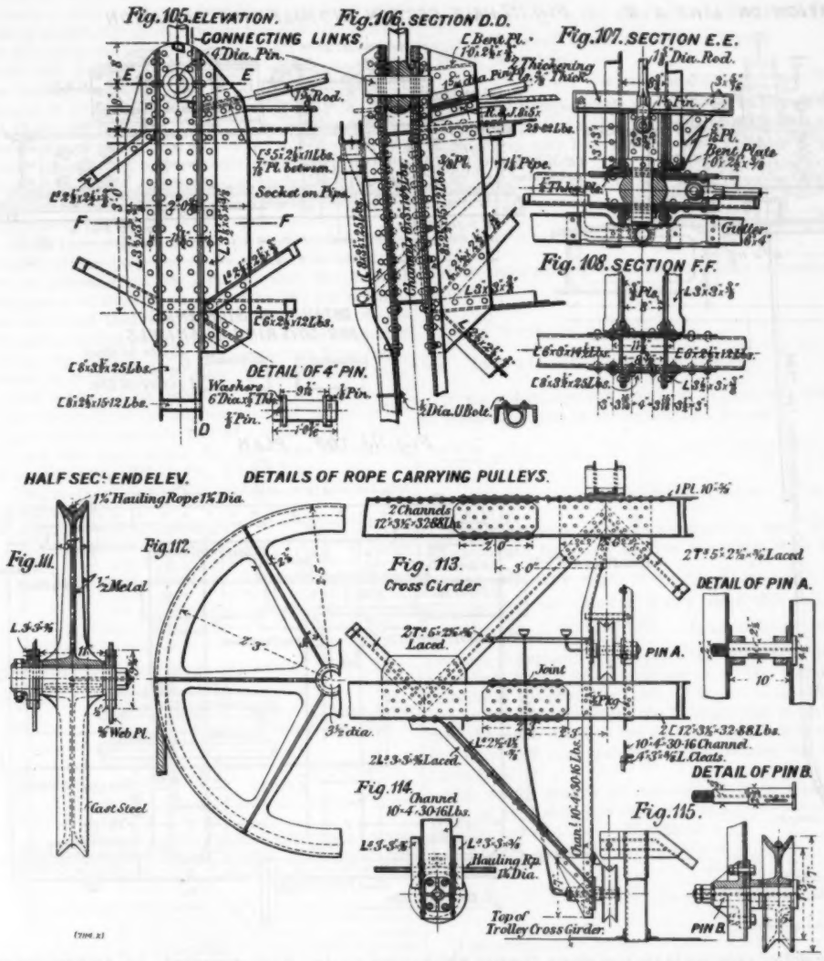


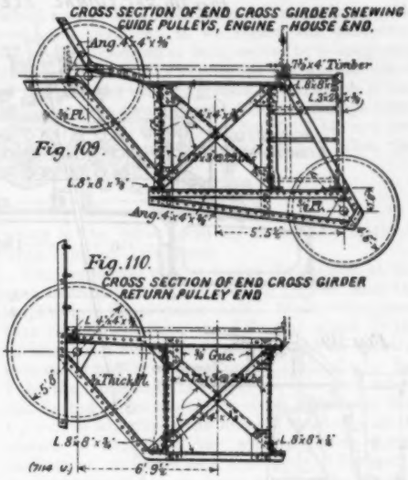

Fig. 103. SECTION

Fig. 104. DETAIL OF JOINT 9.



# DETAILS OF THE RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.





CROSS SECTION OF END CROSS GIRDER SHEWING GUIDE PULLEYS, ENGINE HOUSE END.
Fig. 109.
Fig. 110.
CROSS SECTION OF END CROSS GIRDER RETURN PULLEY END

99 ft. 7⅛ in. high, measured centre to centre of top and bottom pin connections. Details are given of this in Figs. 52 to 68. The main members consist of single 8-in. by 8-in. by ⅞-in. angles with light angle bracing built up in the form of triangular frames, connected, where the main members intersect, by ¾-in. gusset plates. The form taken by the main portions of the frame will be gathered from Figs. 52 and 53, in conjunction with Figs. 59 and 60. Details of the top and bottom extremities of the frames are shown in Figs. 61 to 64 and Fig. 67. Figs. 65 and 66 show the central connection.

The longitudinal distance, from centre to centre, of the trolley pin connections at the top, is 39 ft. 4¾ in., and at the bottom of the frame the corresponding distance centre to centre of bottom suspension links is 30 ft. Transversely the width centre to centre of trolleys is 44 ft. 11½ in., and centre to centre of bottom suspension links 30 ft. 5 in. The upper end of the frame is secured to the trolley girders centrally beneath the bogies, by 6 in. and 4 in. diameter pins, whence the load is equally distributed between the trolley wheels by equalising links and pins. These points will be clear on reference to Figs. 52 and 53. At the bottom end, the suspension frame is stiffened by a pair of horizontal longitudinal and a pair of horizontal transverse trussed members, 3 ft. 6 in. and 3 ft. deep respectively (Figs. 54 and 55, Plate XXV), and connected by 4 in. diameter pins to the 4-ft. links by which the car is suspended. These links are provided with turnbuckles for adjusting the level of the car floor.

The travel of the transporter being effected by steel wire hauling ropes secured to the overhead trolleys, in order to provide against jerks due to inertia of the car and its load, diagonal tie rods, 1⅛ in. diameter, are provided between the bottom longitudinal stiffening members of the suspension frame and the top longitudinal bracing members of the car framing. Each of these tie rods is fitted with spring couplings (Fig. 56) to absorb sudden shocks, each coupling comprising two adjustable steel springs. Similar tie rods are provided transversely, but with turnbuckles instead of spring couplings.

Coming now to the car itself, a view of this is given in Fig. 87, page 287, while Figs. 88 to 108, on pages 287, 288 and the present page, give various details of the construction. The floor system comprises two main transverse single-webbed plate girders, Fig. 88, &c., tapering to a shallower depth at the ends where they are rigidly attached by ⅜-in. web gussets, channels and angles to four upright members. Each girder consists of a ⅞-in. web plate, two 4-in. by 4-in. by ⅝-in. flange angles, and two 15-in. by ½-in. flange plates top and bottom. These girders are spaced 30 ft. apart, centre to centre, and are connected by three longitudinal plate girders, 3 ft. deep (Fig. 89, &c., page 287), with triangular plate-web brackets projecting 5 ft. 6 in. beyond the transverse girders, opposite the ends of the longitudinal girders, and serving as cantilever supports for the end portions of the roadway and footwalks. Pressed steel trough flooring, 5 in. deep and ⅜ in. thick, is laid transversely upon the longitudinal girders, with end sill plates upon which one end of the footwalk troughing, 3 in. deep by ⅜ in. thick, is carried. The ends of the cross-girders support light longitudinal lattice girders, 4 ft. 0½ in. deep, the full length of the car (Figs. 96 and 97, page 288). Above each lattice girder is a steel framing of the same length, 2 ft. 9 in. deep, covered with galvanised steel wire meshing. At each end of the car is a pair of timber framed gates, 4 ft. 1 in. high (Fig. 91), also covered with galvanised steel wire meshing.

The four upright members, which consist of two 8-in. channels, extend upwards at a slight angle, (Fig. 100) and at their upper ends, at a height of 22 ft. 4⅜ in., above tram-rail level, are secured by 4 in. diameter pins to vertical links, 3¾ in. diameter by 4 ft. long, by which they are hung to the main suspension frame depending from the overhead trolleys. The 4-in. pins and brackets are shown in Figs. 98, 105, 106 and 107. The suspension links shown in Figs. 54, 55 and 67 are provided with turnbuckles to permit of vertical adjustment. Transversely, each pair of uprights is cross-braced by a rigid steel arched frame (Figs. 99, 100, &c.), giving a clear height of 18 ft. 10⅛ in. above the roadway. Longitudinal bracing is also provided between the upper ends of the upright members, Fig. 98, with triangular extension brackets to support the ends of the roof. The car is roofed over its full width, from end to end, with curved, galvanised corrugated sheeting, 18 B.W.G.

Beneath the roof and over one of the footwalks is the driver's cabin, measuring 10 ft. long by 5 ft. 2 in. wide, and fitted with switchboard and mountings giving complete control over the electric motors and brakes. The arrangement of windows in the cabin enables the driver to command a clear view in every direction.

Between the upper and lower longitudinal bracing, vertical diagonal tie rods, 1⅛ in. diameter, are introduced (Fig. 53) to transmit the horizontal pull from the main suspension frame to the lower longitudinal bracing of the transporter car. These tie rods are provided with turnbuckles for adjustment.

Having now dealt with the structural part of this transporter bridge, we propose to pass to the arrangements made for hauling the car from one side to the other.

*Hauling Rope and Pulleys.*—The steel wire hauling rope is in two lengths of 670 ft. and 360 ft. One end of the shorter length is secured in a recess in an end groove of the winding drum and (supposing the car to be berthed at the engine-house tower), passes round the drum until one half of the latter is nearly full. From the drum, the rope passes up through the engine-house roof, between the guide rollers, over the lower overhead, 4-ft. 6-in. pulley, Fig. 109, to one of the lever arms of the overhead trolley frame, where it is secured to the spring coupling. One end of the longer rope is secured to the other spring coupling on the trolley frame and thence passes to the other end of the bridge, being supported at every cross-girder by the lower set of 15-in. rope carrying the pulleys, details of which are given in Figs. 113 to 115. At the other end of the bridge it returns round a 5-ft. 8-in.

# DETAILS OF THE RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.

*Fig. 116. SECTIONAL ELEVATION ON LINE X. X.*

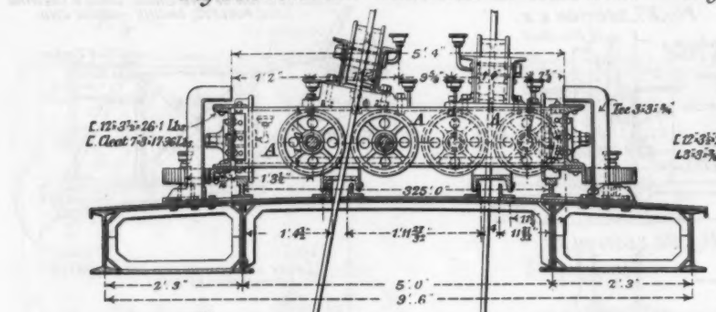
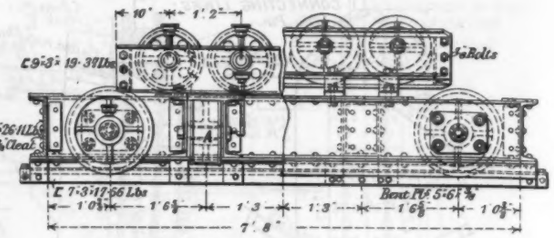



*Fig. 117. HALF SECTION AND HALF SIDE ELEVATION*




DETAILS OF STOP ENDS FOR COVERING CHANNELS

*Fig. 119.*

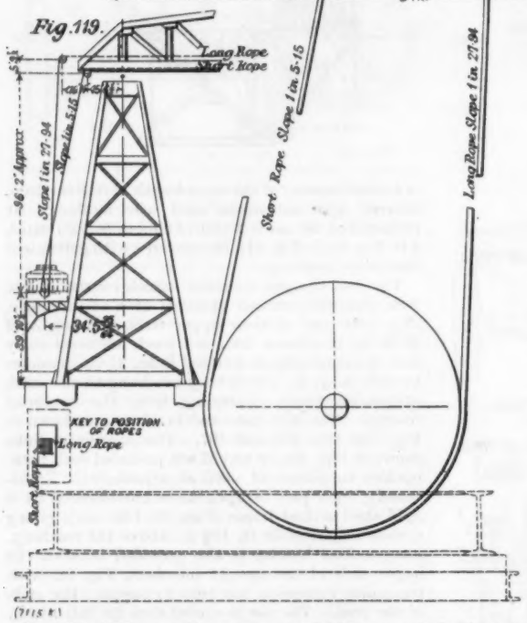
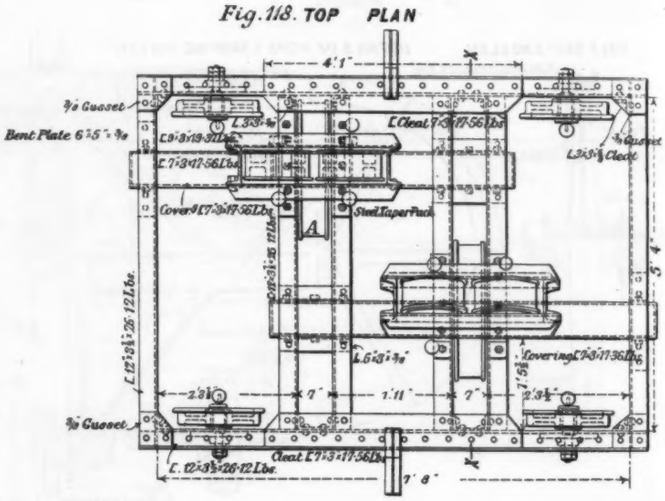



*Fig. 118. TOP PLAN*




pulley, Fig. 110, over the upper set of 15-in. rope-carrying pulleys, Fig. 113, to the engine-house end, where it passes over the upper 4-ft. 6-in. pulley, Fig. 109, and down between the other set of guide rollers, to the other half of the drum round which it takes a safety turn and to which it is secured in the manner already described. The centres of the spring couplings on the trolley lever arm are in the same vertical plane as the rope-carrying pulleys, but at a higher level, so that, as the lever arm passes over the pulleys it clears them. The main rope pulleys, of which drawings are given in Figs. 111 and 112, revolve upon 3¾ in. diameter pins with lubricated bushed bearings carried, on brackets on the end cross-girder.

The rope is 1¼ in. diameter, of extra flexible plough steel, composed of wire of a breaking strength of 115 tons to 120 tons per square inch. The maximum calculated pull upon it, with both brakes acting, is 10·24 tons; normally the braking pull does not exceed 5·12 tons, with one brake acting. The breaking strength of the rope is 45 tons.

*Traversing Rope-Guide Rollers.*—When the hauling rope is wound round the drum or paid out, the angle of the rope, as it passes through the roof of the engine-house, varies. To allow for this, and to prevent the rope from chafing, cast steel rope-guide rollers are mounted on a steel-framed truck with four flanged wheels, which travel upon steel rails supported on the engine-house roof, as shown in Figs. 116 to 119. There are two pairs of these guide rollers to each part of the rope (eight rollers in all), each 12 in. diameter by 5 in. wide, revolving upon 2-in. diameter shafts with bushed bearings and Stauffer lubricators. The frames are built up of 12-in. by 3½-in. rolled steel channels. Beneath the frames a pair of 7-in. by 3-in. inverted channels cover the slotted openings in the roof plates, through which the ropes pass. The truck wheels are of cast steel, 1 ft. 5 in. diameter on tread, with bushed bearings and Stauffer lubricators. To avoid friction between the wheel flanges and rails, horizontal guide rollers are provided with lubricated bushed bearings mounted on the engine-house roof; angle guide rails, riveted to the bottom flanges of the truck channels, bear against these rollers. To prevent the possibility of lifting, a pair of Z-shaped tee-bar brackets is bolted to the roof framing, overlapping the tops of the truck frame channels, with a slight clearance.

*(To be continued.)*

## ON THE MAGNITUDE OF THE FORCES OF RESONANCE IN A TURBINE-DRIVEN STEAMSHIP.

By ALBERT EAGLE, B.Sc., Lecturer in Mathematics in the University of Manchester.

THE recent paper by Dr. J. H. Smith on "Nodal Arrangements of Geared Drives,"* read at the Spring meetings of the Institution of Naval Architects, has drawn attention to the fact that it is desirable to know what is the maximum possible ratio in which a given periodic torque acting on the propeller, could be increased in the propeller shaft and turbine shafts, owing to the resonance of the turbine-gears-and-propeller system with the applied periodic torque.

It is obvious that resonance with any possible harmonic of any possible periodic disturbance cannot always lead to serious consequences, otherwise as has been remarked, no turbine-driven steamship could last for 5 minutes under "full steam ahead."

I first became interested in this problem about three years ago when engaged on the Research Department of the Metropolitan Vickers Electrical Company, Limited. By piecing together some data relating to different ships, I came to the conclusion that the maximum possible ratio in which the amplitude of a periodic disturbance could be increased due to resonance, was only about 10 times. I did not attach much importance to this result, as I was lead by the opinion one instinctively adopts, that anything approaching resonance is serious and is to be carefully avoided by a wide margin in practical working, so that what happens at resonance is a purely academic question of no practical application.

Returning to the subject lately in consequence of Dr. Smith's paper, and working it out as a purely dynamical problem of oscillations about a state of steady motion, I find that the ratio in which a periodic torque acting on the propeller can be increased in the propeller shaft, can be expressed in terms of the usual inertias and elasticities of the system together with two co-efficients which I have called $c_p$ and $c_t$, and which are, respectively, the percentage increase in torque required to increase the speed of the propeller by 1 per cent., while the ship speed remains constant, and the percentage decrease in the torque exerted by the turbine when the rotor speed increases by 1 per cent., the steam flow remaining unaltered. If the turbine is working in the neighbourhood of maximum efficiency the torque will vary inversely as the speed for a constant steam flow so that $c_t$ will be unity; $c_p$ will probably vary considerably for different types of propellers;

* See ENGINEERING, vol. cxiii, pages 438 and 467.

we may perhaps take it as lying between 2 and 4. The results applied to the case of a typical tank steamer lead to some interesting facts. The effective inertia of the four-blade propeller was taken as 425,000 lb./ft.², while the effective inertia at the other end of the propeller shaft was taken as 8,600,000 lb./ft.². The propeller shaft was taken as having a diameter of 19 in. and an effective length of 35 ft. With a shear modulus of rigidity of 12,000,000 lb./sq. in. these figures give the natural frequency of the system as 470 per minute. Calculation shows that any periodic disturbance having the frequency of the propeller blades, which was 280 per minute, acting on the propeller, would be magnified 1·48 times in the propeller shaft.

If all the constants remained unaltered save the length of the propeller shaft which was imagined to be increased to 98·5 ft., so that the natural frequency of the system should be 280 per minute, it was found that any periodic disturbance of this frequency acting on the propeller would be magnified $13/c_p$, say, 3 to 5 times, in the shaft. This ratio, which is certainly not great, is still greater than would generally be obtained, since it is found to vary inversely as the angular twist of the propeller shaft which is here only 1/52 of a radian, as the shaft in this case has a larger diameter than is usual for the power transmitted, viz., 2,750 s.h.p.

The mathematics of the problem may be set out as follows :—

*Symbols.*

$I$ = axial moment of inertia of propeller (+ 25 per cent. for entrained water).
$n\,I$ = axial moment of inertia at turbine end (S.S. gear + turbine), $n = 12$ and 20 for S.R. and D.R. respectively.
$\theta$ = angular displacement of S.S. gear wheel.
$\phi$ = angular displacement of propeller.
$F(\dot\theta)$ = torque exerted by turbine.
$f(\dot\phi)$ = torque exerted by propeller.
$a$ = constant angular velocity (in radians per second) of propeller shaft.
$A\cos pt$ = periodic torque.
$\kappa$ = modulus of rigidity of shaft (torque per unit twist).
$\chi = \frac{F(a)}{\kappa}$ = constant angular twist sans vibrations.
$x$ = small angular displacement (of small amplitude) from steady motion at turbine end.
$y$ = similar small angular displacement at propeller end.
$X$ = quantity such that $x = X e^{ipt}$ is solution of general diff. equa. in $x$ ($y$ eliminated). If not real, its "modulus" (*i.e.*, length of representing vector) is the amplitude of $x$.
$N$ = torque due to oscillation (= 0 during steady running).
$q$ = ratio of $p$ to $\sqrt{\frac{(n+1)\kappa}{n\,I}}$ which is the value at which $x$ becomes infinite, (*i.e.*, resonance) when $c_p$ and $c_t$ are both zero.
$b = \frac{p}{a}$ = number of propeller blades.

Let I be the axial moment of inertia of the propeller, including in this term the effective inertia of the water which the propeller drags with it when oscillating. This correction, which is not known accurately, is generally taken as 25 per cent. of the inertia of the propeller itself. Let $n\,I$ be the effective inertia at the other end of the propeller shaft; that is the inertia of the low-speed gear wheel together with $s^2$ times the inertia of any body which is geared with it and revolves with $s$ times its angular velocity. For single and double-reduction gears $n$ will be in the neighbourhood of 12 and 20 respectively.

Let $\theta$ and $\phi$ be the angular displacements of the turbine and propeller end of the propeller shaft, and let $\kappa$ be its rigidity. The torque exerted by the turbine, and the resistance offered by the propeller, may be denoted by $F(\dot\theta)$ and $f(\dot\phi)$ respectively, where the dots signify differentiation with respect to time.

If, further, we write $A\cos pt$ for the periodic torque which we suppose acting on the propeller, the equations of motion may be written :

$$n\,I\ddot\theta = \kappa(\phi - \theta) + F(\dot\theta)$$

$$I\ddot\phi = \kappa\,(\theta - \phi) - f(\dot\phi) + A\cos pt.$$

Let $a$ be the constant angular velocity of the propeller shaft given by these equations when $A = 0$. Then $F(a) = f(a)$ and we may write the solution :

$$\theta = at + \chi \quad \text{and} \quad \phi = at.$$

where $\chi \equiv \frac{F(a)}{\kappa}$ is the constant angular twist in the propeller shaft due to the driving torque.

When $A \neq 0$ let

$$\theta = at + \chi + x \quad \text{and} \quad \phi = at + y,$$

where $x$ and $y$ respectively represent the oscillations, which are supposed to be of small amplitude so that their squares may be neglected. We have then :

$$F(\dot\theta) = F(a + \dot x) = F(a)\left\{1 - \frac{c_t\,\dot x}{a}\right\} = F(a) - \frac{c_t\,\kappa\,\chi\,\dot x}{a}$$

$$f(\dot\phi) = f(a + \dot y) = f(a)\left\{1 + \frac{c_p\,\dot y}{a}\right\} = f(a) + \frac{c_p\,\kappa\,\chi\,\dot x}{a}$$

With these substitutions the equations of motion become :

$$\left.\begin{aligned} n\,I\ddot x &= \kappa(y - x) - \frac{c_t\,\kappa\,\chi\,\dot x}{a} \\ \text{and}\quad I\ddot y &= \kappa(x - y) - \frac{c_p\,\kappa\,\chi\,\dot y}{a} + A\cos pt \end{aligned}\right\} \quad . \quad . \quad (1)$$

If we substitute the value of $y$ from the first of these equations in the second one, we get :

$$\frac{n\,I^2}{\kappa}\ddddot x + \frac{I\,\chi}{a}(c_t + n\,c_p)\dddot x + \left\{(n+1)\,I + \frac{\kappa\,\chi^2 c_p \cdot c_t}{a^2}\right\}\ddot x + (c_p + c_t)\frac{\kappa\,\chi}{a}\dot x = A\cos pt \quad . \quad (2)$$

If we put both $c_p$ and $c_t$ equal to zero this equation will be found to give resonance with an infinite amplitude when $p^2 = (n+1)\frac{\kappa}{n\,I}$. Let us suppose that the value of $p$ is $q$ times this value, so that $p^2 = \frac{(n+1)\,\kappa\,q^2}{n\,I}$. Inasmuch as the periodic disturbance arises from the rotation of the propeller, $p$ will be a multiple of $a$, the angular velocity of the propeller shaft. Let $p = b \cdot a$, where $b$ is an integer, which for the fundamental periodic disturbance is equal to the number of blades of the propeller, and is a multiple of this number for the harmonics.

The usual manner of solving (2) is to replace $A\cos pt$ by $A\,e^{ipt}$, and assume $x = X\,e^{ipt}$, where X is not necessarily real. This gives

$$\left.\begin{aligned} &p^2\left\{\frac{n\,I^2}{\kappa}\cdot p^2 - (n+1)\,I - \frac{\kappa\,c_p\,c_t\,\chi^2}{a^2}\right\} \\ &- ip\left\{\frac{(c_t + n\,c_p)\,I\,\chi\,p^2}{a} - (c_p + c_t)\frac{\kappa\,\chi}{a}\right\} = \frac{A}{X} \end{aligned}\right\} \quad (3)$$

If we eliminate $a$ by means of the relation $\frac{p}{b} = a$ and substitute for the value of $p$ we get, for the modulus, or amplitude, of X :

$$|X| = \frac{A/\kappa}{\sqrt{\left\{\frac{(q^2 - q^4)(n+1)^2}{n} + b^2 \cdot c_p\,c_t\,\chi^2\right\}^2 + b^2\,\chi^2\left\{\begin{matrix} c_t\,(1 - q^2 - q^2/n) \\ + c_p\,(1 - q^2 - n\,q^2)\end{matrix}\right\}^2}} \quad (4)$$

What we actually require is the amplitude of the oscillatory torque in the propeller shaft, which is $\kappa\,(y - x)$. By the first of equations (1) this is equal to :

$$n\,I\ddot x + \frac{c_t\,\kappa\,\chi}{a}\dot x = N,$$

say.

Writing $x = X\,e^{ipt}$, we get :

$$N = \left\{-n\,I\,p^2 + \frac{i\,c_t\,\kappa\,\chi\,p}{a}\right\} X e^{ipt}.$$

Writing $a = \frac{p}{b}$ as before, and substituting for $p$, we find that the amplitude of N is :

$$\kappa\sqrt{(n+1)^2\,q^4 + b^2\,c_t^2\,\chi^2} \quad . \quad . \quad . \quad (5)$$

times the amplitude of X.

The worst case in practice will be *very nearly* when $p$ has the value, which in the absence of the damping terms $c_p$ and $c_t$, will give resonance with an infinite amplitude; that is, when $q = 1$. If we put $q = 1$ we find that the amplitude of the periodic torque in the propeller shaft is :

$$\frac{\sqrt{(n+1)^2 + b^2\,c_t^2\,\chi^2}}{\sqrt{b^4\,c_p\,c_t^2\,\chi^4 + b^2\,\chi^2\left(\frac{c_t}{n} + n\,c_p\right)^2}} \quad . \quad (6)$$

times the amplitude of the periodic torque acting on the propeller. Since in practice $(n + 1)$ is large compared with $b\,\chi\,c_t$, and also with unity, this reduces to the very simple expression :

$$\frac{1}{b\,\chi\,c_p} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

which may be taken as the limit of possible magnification in practice. If we regard the particular harmonic considered as being caused by $b$ imaginary propeller blades, $b\,\chi$ represents the angular twist in the propeller shaft expressed as a fraction of the angle between two adjacent blades. Except when $q$ is nearly equal to unity we find from (4) and (5), since $b\,\chi\,c_t$ is small compared with $n$, that the magnification is given by :

$$\frac{n}{n+1}\cdot\frac{1}{1 - q^2},$$

which is the value given by elementary methods when damping is neglected.

The amplitude of the torque fluctuation at the gear teeth can easily be seen to be less than the amplitude in the propeller shaft. We have supposed that the system from the S.S. gear wheel to the turbine has a negligible flexibility, and an effective moment of inertia at the propeller shaft of $n\,I$. Let I be the moment of inertia of the S.S. gear wheel, and $I_r$ that of the remainder of the system, so that $I_g + I_r = nI$. Since the internal flexibility of the system is negligible, the whole system, during oscillations, oscillates as a rigid body. Further, it is clear from the above formulæ, that the effect of the force due to the $c_t$ term is quite inappreciable in practice, so that its existence can be neglected altogether. Hence we see that the amplitude of the periodic torque acting on the part $I_r$ (which is the torque on the S.S. gear teeth) is to the amplitude of the torque acting on the whole system $I_g + I_r$ (which is the torque in the propeller shaft) as $I_r$ is to $I_g + I_r$. Since in practice the $I_g$ is small compared with $I_r$, this ratio is sensibly unity.

It should be noted that the magnification given by (6) is often very small; $\chi$ the angular twist in the propeller shaft is frequently as great as 1/20 of a radian, and hence for a four-blade propeller the magnification cannot exceed $\frac{5}{c_p}$, which is, probably, generally less then 2. In a four-blade propeller we can hardly imagine that the resistance to the propellers motion falls below 75 per cent. of its normal value four times per revolution, hence the torque in the propeller shaft cannot fall below 50 per cent. of its normal value or rise above 150 per cent., even though the ship is running dead on its synchronous speed. It is clear that this cannot cause any separation of gear teeth or be very destructive to them.

There is no doubt that the enormous forces produced by very slight irregularities of the gear teeth—which can easily exceed 10 times the normal load for a tooth error of no more than 0·001 in.—when two wheels of large inertia and running at a high speed, are geared together, is the main source of the trouble in many geared turbine-driven ships. To avoid this trouble, each *pinion wheel should always be connected through as flexible a shaft as the torque to be transmitted and the available length at the designer's disposal permit of.*

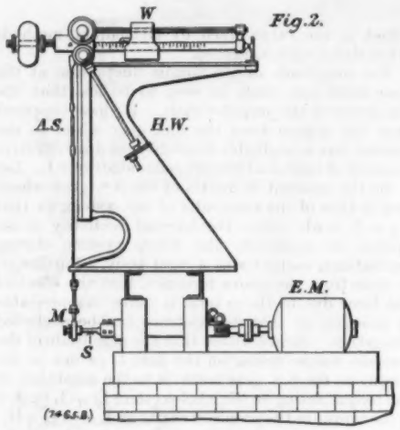
It appears that the necessary diameter required by the driving torque to be transmitted, and the shortness of the space available, prevent these shafts from being so flexible as to introduce into the system fresh free periods in synchronism with the disturbances due to the propeller blades.

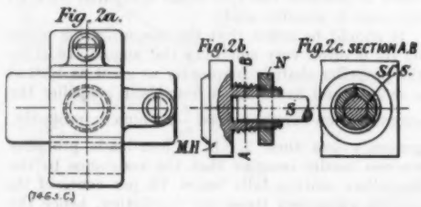
This conclusion is, of course, diametrically opposed to that given by Dr. Smith in the paper above referred to, who regards any and every conceivable possibility of resonance as capable of producing destructive forces and omits altogether the forces that must necessarily arise whenever the gears are not geometrically perfect.

## ELASTIC LIMITS OF COPPER UNDER CYCLICAL STRESS VARIATIONS.

IN our recent comments on the work of the National Physical Laboratory we briefly referred (on page 7 *ante* of our issue of July 7), to Mr. H. Gough's remarkably rapid method of determining the fatigue range of stress from a test on a single specimen. This method reduces the time necessary to predict the limiting stress to less than half an hour. The experiments were first made with Swedish iron and Armco iron, and were then extended to a carbon steel, a case-hardening

steel, pure nickel and a phosphor bronze. These latter materials all gave similar yield-range curves on an ordinary Wöhler fatigue-testing machine, when the specimen—which was hollow in the first tests—was rotated about its horizontal axis by an electric motor at 2,200 r.p.m. A plane mirror was affixed to the non-rotating ball bearing, the load being applied through a stirrup to the ball bearing which was supported on the overhanging end of the specimen. The

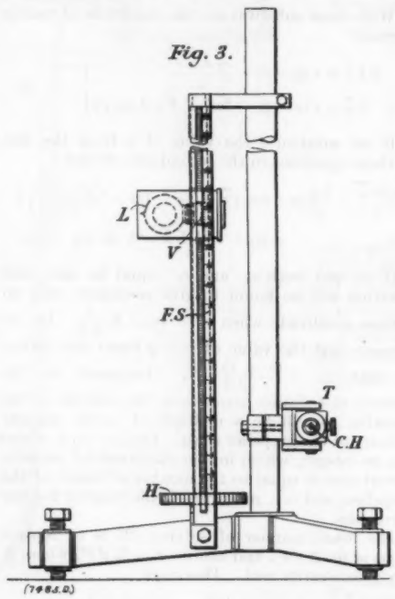


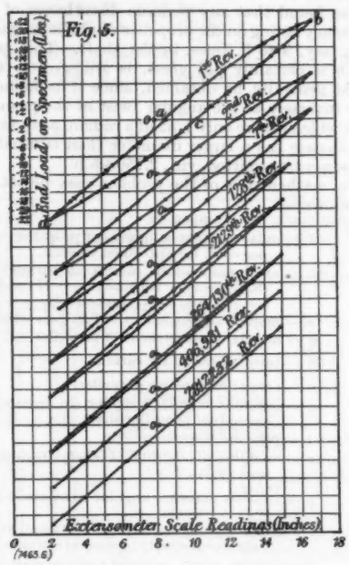

in the Metallurgical Department of the Laboratory. The three cast specimens gave the following analyses and tensile test results :—

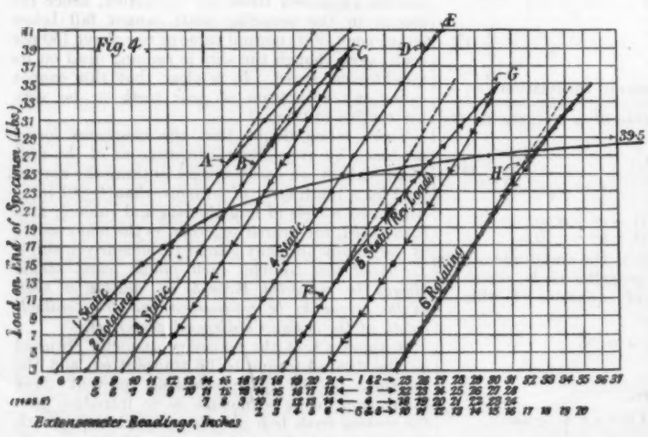
| Cast No. | Copper. | Oxygen. | Ultimate Stress. | Elongation. |
|---|---|---|---|---|
| C. 28 G. | 99·96 | 0·04 | 13·0 | 60·0 |
| C. 27 G. | 99·91 | 0·09 | 13·4 | 52·5 |
| C. 30 G. | 99·94 | 0·06 | 13·1 | 56·0 |

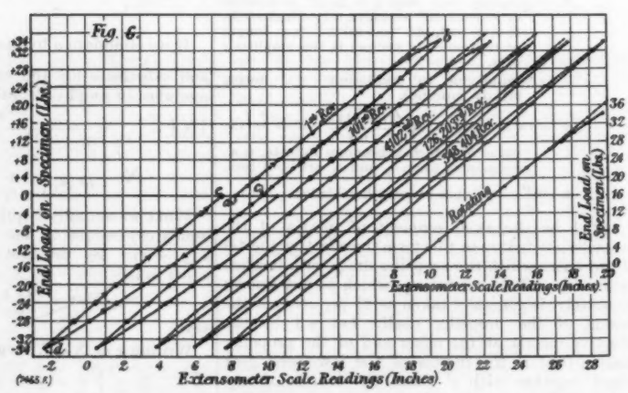
The ultimate stress is expressed in tons per square inch, the elongation in per cents., as are also the proportions of copper and oxygen. The tensile tests recorded typical plastic-load elongation, no limits of proportionality or yield points. The copper was rolled cold from ½ in. to ⅜ in. diameter, annealed for 30 minutes at 700 deg. C. and cooled in air. The form of specimen used is shown in Fig. 1, on which the range of the points P of applying the load is marked. Figs. 2, 2*a*, 2*b*, and 2*c* illustrate the Wöhler machine. The specimen S to be tested (shown in position in Fig. 2*c*), is solid, not hollow, the previous experiments having proved that the form of the specimen is immaterial, so that the machining of hollow specimens was unnecessary. The diameter is 0·4 in. at the point of maximum stress. In the machine the specimen forms a cantilever which is rotated by a direct-coupled electric motor E.M. A single lever weighing machine W of 150 lb. capacity is mounted on the top of the Wöhler machine, and the load is applied by means of a hand wheel H.W.; it acts on the specimen through a rod with adjustable screw A.S., and through a stirrup and ball bearing. A stainless mirror M is affixed to the end of the specimen; by means of a fitting provided with double adjustment the plane of the mirror can be made perpendicular to the axis of the specimen. The mirror holder M H (Figs. 2*a*, 2*b*, and 2*c*) terminates in a taper-screwed socket S C S (split by three sawcuts) fitting over the end of the specimen S, and the nut N gripping the taper screw binds the mirror holder to the end of the specimen.




The measuring device, of which Fig. 3 gives a front elevation, was designed and constructed in the Engineering Department. It consists of a stand to which a telescope T can be clamped in any position. A bracket carrying a lamp L with a point source of light can be raised and lowered in a vertical plane by means of the hand wheel H; the diagram shows the fixed scale F.S. and the vernier V, by the aid of which the position of the bracket can be read to 0·01 in. The image of the lamp, reflected by the mirror, is focussed on the cross-hairs C.H. of the eyepiece of the telescope T. When during a test the load is altered, a change occurs in the slope of the plane of the mirror; the position of the lamp is then adjusted vertically, by means of the hand wheel, until the image of the lamp is again seen on the cross hairs. The change in the position of the lamp is thus a measure of the change of slope of the end of the specimen, and the scale readings plotted against the corresponding loads give the "load-slope diagrams."




elastic limits of iron and steel under cyclical variations had previously been investigated at the Laboratory by Professor L. Bairstow (Philosophical Transactions, A, vol. ccx, 1910); the materials of those researches were such that the limiting range of stress under reversal lay within the primitive elastic limits. A second type of material (nickel), in which the limiting range under reversed direct stresses is greater than the range of the primitive elastic limits had recently been studied by Mr. G. A. Hankins. When Mr. Gough extended his experiments to copper, he made some noteworthy observations. Copper has no primitive elastic limit or yield-point; it undergoes large plastic strains with the application of small loads. But subjected to the reversed bending stresses of Mr. Gough's machine, the copper became elastic, and the original large hysteresis loop observed vanished. On these researches Mr. Gough has presented a report to the Elasticity and Fatigue Panel of the Aeronautical Research Committee; we summarise this report.

The material used was a copper of high purity prepared

The distance of the measuring apparatus from the mirror is 46 ft.

In testing a new C. 28 G. specimen the load was increased by regular steps and the slope was measured at each load. The resulting curve—practically identical with curve 2, Fig. 4, which belongs to another set—is typical for this test and shows that the slope was proportional to the load up to a load of 25 lb; at 27 lb. and subsequent loads, an increasing deviation from the straight line was observed. Taking the breakdown point at a load of 26 lb., the corresponding stress would be ± 5·5 tons per square inch. According to Bairstow (*loc. cit.*) the total extension at any range of stress is, for materials stressed between equal and opposite limits of stress, composed of a total elastic extension plus a cyclical permanent set. Hence if it be assumed that the width of the hysteresis loop, at ranges below the limiting fatigue, is either zero or is small and proportional to the imposed range, the deviation from the apparent elastic line may be taken as a measure of the width of the hysteresis loop at the time at which

the reading was recorded. The number of reversals of fracture at any extra-elastic range would probably depend upon a certain maximum amount of extra-elastic work which unit-volume of the material can sustain before fracture. The width of the hysteresis loop should then be related to the number of reversals to fracture, and useful results might be obtained by comparing the relation between this horizontal intercept and the number of reversals to fracture at the corresponding range of stress.

During the test just mentioned and similar tests the following interesting phenomenon was observed. During the elastic period the mirror moves in a truly vertical plane, the light spot travelling along the vertical cross-hair. When the fatigue-limiting range has been exceeded, the light spot moves off the vertical cross-hair, showing that the specimen has assumed a curvature. In a particular case the lateral deviation became so great that the measuring apparatus had to be shifted by as much as 2 ft. An endurance test was then made on the same specimen, with an end load on the specimen of 24·6 lb., corresponding to a stress of 5·25 tons per square inch; at 9,760,000 reversals the specimen remained unbroken. It broke, however, with a load of 28·6 lb., corresponding to a stress of 6·06 tons per square inch, and 1,620,000 reversals.

A static bending test was then carried out, performed with a new specimen of the same copper, the motor shaft being clamped; in this case the curve obtained, Fig. 4 (1), is that of a typical visco-elastic material. When the load had been reduced to zero, the specimen was found to be slightly bent. A load of 2 lb. was next placed on the specimen and the motor shaft was slowly turned; after a few reversals the specimen ran truly. The motor was then put to full speed, 2,200 r.p.m., and a rotating test was taken; the curve obtained was that of Fig. 4 (2), already referred to; the deviation from the straight line sets in at A, corresponding to a fatigue range of ± 5·54 tons per square inch. With the specimen still rotating the range was gradually reduced to zero and the machine then stopped; the motor shaft was once more clamped, and a new static bending test was carried out. Curve Fig. 4 (3) thus obtained is practically a repetition of curve 4 (2); the line is straight until the elastic limit is reached at B, which corresponds to the same fatigue range as A on curve 4 (2). Thus a new method of obtaining the fatigue range was indicated. The result of the method, it was subsequently shown, depends entirely on the fact that an extra-elastic range of stress is slowly reduced to zero. The range of artificial limits is thus slowly reduced to its minimum value, *i.e.*, the fatigue range; a subsequent static test discovers one limit as an elastic limit effect. The result may be said to constitute a further demonstration of Bauschinger's theory.

The maximum stress applied during this last test, at C, Fig. 4 (3), was 8·31 tons. The load was removed and the specimen again loaded statically; curve Fig. 4 (4) obtained was again straight (though it does show a slight curvature) up to the point D, which is on a level with C; then the curve deviated, the maximum stress applied at E, being 8·74 tons per square inch. This stress was removed, and the specimen was allowed to rest for an hour. If this interval of rest had been sufficient, a superior elastic limit (of 8·74 tons) would have been produced, and if the loading were reversed an inferior limit should be produced, the range between these limits being the natural range at the given maximum applied stress (Bauschinger, Bairstow, &c.). The load was now reversed. With the apparatus used the most convenient way of reversing the load was to rotate the specimen through 180 deg.; this was done, the spindle was once more clamped, and a static test was carried out. The curve Fig. 4 (5) (reversed loading), is straight up to point F (2·36 tons per square inch). The range of elastic limits between E and F is 11·10 tons per square inch, while curve 4 (2) shows that the natural range for reversed stresses is 11·08 tons per square inch. A further rotating test was then performed; the curve Fig. 4 (6) is practically a repetition of Fig. 4 (2), the point H occupying the same position as A, thus indicating that the fatigue range has not been affected by the intervening experiments. There is, however, one difference. When we look at the horizontal intercept between the (produced) elastic line and the deviating slope, we see that the intercept is less in Fig. 4 (6) than it is in Fig. 4 (2) at the same range. That would suggest that the width of the hysteresis loop would diminish with prolonged stresses, and the hysteresis loops were, therefore, further investigated both within and outside the limiting range of stress.

The material used for these tests was the C. 27 G., which, it will be seen, was a little richer in oxygen and gave a higher ultimate stress and a smaller elongation than the copper of the tests so far mentioned. The curves found were similar in all respects, and the fatigue range (5·54 tons per square inch) was the same. In the static tests care was taken always to clamp the motor shaft in such a position that the fibres under maximum stress were the same; reversed loadings were applied as before by giving the specimen half a turn in the socket. The maximum limiting stress being 5·54 tons per square inch, the hysteresis loops within the "natural range" were examined for a stress of ± 4·70 tons per square inch (corresponding to a load of ± 22 lb.), while the loops in the "extra-elastic region" were examined for stresses of 7·24 tons per square inch (load of ± 34 lb.).

The loops were all traced in like manner (Fig. 5). Starting at *a* (zero load) the load was increased by regular steps up to *b*, then reduced to zero again at *c*; the specimen was rotated through 180 deg., and the load increased to *d* and reduced again to zero. Within the natural range all the loops were of the type described by Bairstow. The portions *a b* and *c d* are regular curves, while *b c* and *d a* are straight lines indicating elastic extension. The width of the loop *a c* is the cyclical permanent set of Bairstow, and the total extension for any range should be equal to the cyclical permanent set plus the elastic extension for that range. Not all the loops were closed; our Fig. 5 shows a distinct gap in the curve, as observed after the first and second reversals; after the 128th reversal the gap was barely perceptible; after the 466,931st reversal the cyclical permanent set had vanished and the curve had shrunk into a straight line; the 2,812,232nd reversal gave the same straight line. It is rather remarkable that a material like pure copper should become really elastic under static loading, even though it has a definite fatigue range under stress reversals at high frequency. It seems probable that visco-electric strains would result under prolonged loading at stresses below the limiting range, even after the material has been brought to the state of these specimens after nearly 3,000,000 reversals.

In the first hysteresis loop for the extra-elastic region (maximum stress ± 7·24 tons per square inch) the curve (Fig. 6) was straight from *a* till a definite load (26 lb.) was reached, when the line curved round to *b*; the position *b c* was almost entirely straight; *c d* was regularly curved, and *d e* similar to *b c*. This test completed, the specimen was straightened, the motor was run at full speed, and the jockey weight shifted to maximum load; after the desired number of reversals the weight was run back to zero load, and the machine stopped. The curves thus obtained (up to 348,404 reversals) were all similar, as shown in Fig. 6; the cyclical permanent set diminished as the reversals increased. A rotating test then made on this specimen again yielded the original curve of Fig. 4 (2); the specimen finally broke after 900,000 reversals at a load of 24 lb.

The extensometer measurements proved that within the elastic range the total extension decreased from 14·7 in. to 12·8 in. as the number of reversals increased to nearly 3,000,000, making a mean elastic extension of 12·8 in. or of 0·58 in. per unit load, whilst in the extra-elastic range, the total extensions decreased from 22 in. to 20·9 in., as the reversals increased to 348,404, giving a mean elastic extension of 20·2 in. or again of 0·59 in. per unit load. The cyclical permanent set decreased from 1·8 in. to 0 in the former case and from 2·1 in. to 0·8 in. in the latter. The experimental data agreed within 0·1 per cent. In the determination of the hysteresis loop for a material which has been subjected to a number of cyclical variations of stress over an extra-elastic range the change from the alternating stress test to the static test may be effected in three different ways: I, the machine may be stopped at the superior limit of stress, and the load be reduced to its mean value; II, the machine be stopped at the inferior limit of stress, and the load reduced to its mean value (this would give the Bairstow curve); III, the range of stress may be slowly reduced to zero and the machine then stopped (the present method). The three methods of procedure should modify the character of the loops with respect of the various portions *a b*, *b c*, &c., and the expected modifications were observed in further experiments. We are glad to hear that a continuation of these interesting investigations is in progress.

## THE STRENGTH OF RAILWAY BRIDGES

*The Strength of Railway Bridges, with Special Reference to the Proposals of the Ministry of Transport.**

By A. C. COOKSON, M.Inst.C.E., and J. S. NICHOLAS.

THE Ministry of Transport has had under consideration recently the revision of the old Board of Trade rules for the opening of railways, and several additional regulations are proposed which are of considerable interest to engineers and not a little disturbing to many. The section dealing with the strength of bridgework, and more especially the proposed new regulation regarding an allowance to be made for impact, is of particular interest to the authors who are, and for many years have been, engaged on the design, construction and maintenance of steel structures.

The Ministry are desirous of carrying the railway engineers with them in their new proposals, but on the particular rules relating to maximum permissible stresses and methods of calculation they have not, so far, been entirely successful. It is because the authors think that new rules on such an important question relating to the public safety should not at the present moment be promulgated, that they venture to present some evidence gathered recently by them, in the hope that they may induce some better joint action between leaders of scientific research and engineers responsible for the maintenance of British railways.

They suggest that although there are many points of design which are at present determined by experience, judgment or precedent these might, after proper investigation, be made matters of comparatively simple calculation.

One such matter has had extraordinary prominence given it in recent years—in fact, seems to recur at intervals as though it were a new discovery requiring immediate solution. It is, "What provision shall be made in any bridge for a load passing over at speed, as compared with the same load at rest on the structure?" The early engineers were confronted with this problem and had their own practical solutions. All engineers are aware of the work of Fairbairn and of the Royal Commission in 1847.

The question of the strength of wrought-iron bridges received much prominence as a result of the refusal of the Government inspector to sanction the opening of the Torksey Bridge in 1857(†), and in 1859 the Board of Trade issued an instruction that 5 tons per square inch was to be the maximum permissible stress in tension. The matter of "impact" as it is called to-day by many was not mentioned as such, and it is frequently said of these rules that no provision was made for impact, or at least that it was insufficiently appreciated.

We do not think that any person engaged in the maintenance of a British railway will hold such views, as he has ample evidence with which to controvert them. Many cases of old bridges will occur to the minds of such men as certain proof that the designers were well aware of all that would be asked of their creations. It was probably a most wise proceeding in view of the state of our knowledge in those days to give, what was no doubt intended to be, no more than a general hint as to maximum permissible stress.

Since those early days the general practice of engineers has been to adopt 5 tons per square inch as the maximum stress in the larger members of iron structures, and, in order to get the same life out of the smaller members more intimately associated with the actual wheel loads to reduce to 4 tons or even 3 tons where considered necessary.

Although the word "impact" was not mentioned in the old Board of Trade rules, it is certain that the figure of 5 tons was fixed as the stress which would be quite safe in the structure under any conditions of engines and track, and at any attainable speed. The rule has been styled "mediæval," but at any rate it permitted a certain latitude in design by the study of which we to-day are more truly advised of the proper proportions of such structures than by present-day theory.

In 1877 mild steel was coming into favour and the permissible stress was raised in cases where this material was used to 6½ tons as a maximum.

When this addition was made the Board of Trade must have known that engineers generally were making some such reduction of stress as has been previously referred to, yet, and as we think rightly, no attempt was made to fetter engineers by the introduction of special rules for varying spans or subsidiary portions of structures, such matters still being left to their individual judgment. Although in 1871 the results of Wöhler's tests on the endurance of iron and steel had been published there was no general agreement as to the applicability of his conclusions to the problem of carrying loads at speed over bridges. To-day even there are engineers of distinction who are convinced that the principle enunciated, viz., "that the range of stress is the principal factor in determining the endurance of metal," has no bearing on the question—others give it first place in their own subsidiary rules.

In the detail treatment of a bridge structure therefore we find that scarcely any two railway engineers agree, and we refer briefly to what we may call the two schools of thought on the live load question, viz.: First, those who increase the actual amount of the live load by some formula or other and work to a constant stress; second, those who use the actual engine weights and reduce the working stress by a formula embodying either the results of their own experience or the conclusions of well-known research workers.

It has only recently been learnt by many of the first group that the increment method is simply the procedure of the second group inverted, which inversion appeared to its author to be more convenient for drawing office use. If this had been realised earlier much discussion might have been avoided.

The immediate urgency of the "impact" question is, we believe, due to action taken by the Indian engineers in 1903. The rule favoured for Indian bridgework was that known as the "Pencoyd," and in 1912 we read that it was suspected that the formula made insufficient provision in small spans and the reverse in spans over 50 ft. We have not been fortunate enough to discover the evidence for this suspicion, but it was sufficient to induce the bridge experts in India to take up the point with the intention of putting it, if possible, upon a scientific basis. Their admirable procedure is known to many, and may be read in the reports of the "Indian Railway Bridge Committee," published as Technical Papers by the Railway Board in India.

* Paper read before Section G of the British Association at Hull, September 7, 1922.

Experiments are being conducted by highly-skilled and specialised engineers, and we look forward hopefully to their final report.

The Ministry of Transport, being engaged on the revision of rules for railways, determined to carry out experiments on British bridges, with the object of standardising practice. The results are published as a report by Major (now Lieutenant-Colonel) Mount to the Chief Inspecting Officer, Colonel Pringle.

Speaking broadly, the report concludes that the "suspicion" of the Indian engineers was justified and the rule as to "impact effect" propounded by that officer will have the effect of making all new bridges of small span heavier than those designed by many engineers to-day, and regarded by them as being amply strong for actual present and probable future requirements. In effect it says that these engineers have not sufficiently appreciated the live load effect. If this were true some rules should have been propounded to deal with existing bridges. At the moment it is entirely a matter of judgment for the engineer as to how long a bridge is to remain in service, and, to attain an uniform standard, some maximum amount of overstress should have been fixed with a view to the early elimination of the weakest structures.

If the proposed rules of the Ministry are passed even with a considerable margin for overstress a very large rebuilding programme will have to be undertaken by most railways, although their engineers are annually certifying the safety of these very structures.

As an illustration of the effect of the proposed rule as compared with the present practice of one railway the percentage increase required at zero span is 36; therefore we are entitled to re-examine the question in the light of knowledge acquired from actual structures in use to-day most of which appear to refute the suggestion of inadequacy for the particular purpose.

The officer in charge of the experiments, with the expert assistance of the inventor of the Fereday-Palmer stress recorder, obtained measurements of actual stresses under heavy engines at varying speeds. These were compared, and the difference between the highest stress obtained at speed and the lowest stress (that obtained by the engines crawling) was regarded as due to impact effect and the percentage noted.

The first thing the practical maintenance man looks for in this report is the maximum stresses obtained, and he is not much concerned at what speed they were obtained. Turning to rail-bearers, which he supposes would be stressed by a heavy engine standing on them to 3 tons or 3½ tons, possibly more, and fully expecting that under speed conditions a sensible increase would be recorded, what does he find? Taking rail-bearers as a group by themselves no "high" stresses were ever reached. Averaging the tests in this group we get the following results: Representing the "calculated" static stress as 100 we find the average "observed" static stress to be 46, and the average maximum observed stress at speed to be 77, *i.e.*, giving an average percentage increase of 67. This remarkable disparity between calculated and observed stresses, although not altogether unsuspected, is now for the first time fully revealed to all who read the report.

The reporter suggests that the calculated stresses are not reached because in such members (rail-bearers) partial fixity of ends, and other factors, tend towards reduction. These suggestions are not very convincing, however, for turning to the group of "plate girder flanges" it will be admitted that there is little fixity of ends of plate main girders, but the discrepancy here is equally as great as in the rail-bearer group. Taking the average of 21 tests, and representing the "calculated" static stress as 100, we get the "observed" static stress as 56 and observed maximum stress at speed as 80. It is permissible here for anyone reading the report to suspect the instrument of inaccuracy, but quite similar results are got with another and simpler instrument which will be mentioned later; therefore we accept broadly the amounts recorded. The officer was, however, engaged in discovering an impact coefficient for various spans, and like many an earnest seeker he found what he required. It was quite natural that beginning with (probably) the "suspicion" that 100 per cent. impact was insufficient on very small spans one solitary result of 159 per cent. was embraced as "proof."

It has been noted by persons taking stress measurements on actual structures that occasionally there are one or two results, out of many, that are, when plotted, far away from the group, and it has been their practice to ignore them or, at least, to pay them small attention when deducing a conclusion.

It is greatly to be regretted that the officer thought fit to make use of this extraordinary result, the majority being far below this figure. In his own justification he reports that as the experiments were not numerous it is by no means certain that the highest results were obtained. True—then they should have been continued, or recommendation postponed. Either sufficient reason for the discrepancies noted should have been offered, or the making of even a tentative rule dropped. The authors have taken hundreds of measurements in the last three years with a strain-gauge believed to be reliable, and on which the result can be read as soon as the load has passed off the structure, the maximum stress only being observed. As has happened in France, we have been able by a study of these results to advise the retention in service of structures scheduled for reconstruction on the basis of calculations only.

No value is placed upon a single reading, the experience being that extraordinary readings can be got at certain spots. Generally six or seven readings are got from each of a pair of gauges worked side by side. In the case of one bridge, the reconstruction of which had been delayed owing to the war, observations were made for two and a-half days on two cross-girders with the idea of ascertaining the highest stresses encountered. The cross-girders were chosen because they were in the vicinity of joints both in rails and longitudinal sleepers, and also because on calculations they were known to be relatively weaker than several girders on similar bridges in the vicinity. This case will be referred to at length. It is a bridge of three spans carrying a double line of way, and, in cross-section, a "three-girder bridge." Reference to Fig. 1 will show cross-girders at spacings of 4 ft. and on top of these the timber decking is laid diagonally. The permanent way is heavy section bull-head rails carried on specially deep longitudinal beams, and there is a little ballast between decking and longitudinals for packing purposes (see Fig. 2). Joints in the longitudinals are spliced as shown. A diagram is shown of the engine under which the maximum stress was recorded. It will be recognised that to determine reactions for individual cross-girders in these circumstances is not an easy matter. In the course of ordinary office procedure some assumptions are made to expedite the calculations. The maximum reaction of one cross-girder, near the joint in the longitudinal timber, was assumed as equivalent to the imposition of an 18-ton axle. From this load, calculated on the ordinary assumption of free ends, and using the tension modulus of the section, a static stress of 11 tons per square inch was obtained. The results, several of which are given in Table I, vary very consistently with the weights of the engines, the maximum it is interesting to note was recorded with the 2-8-0 engine running light. The

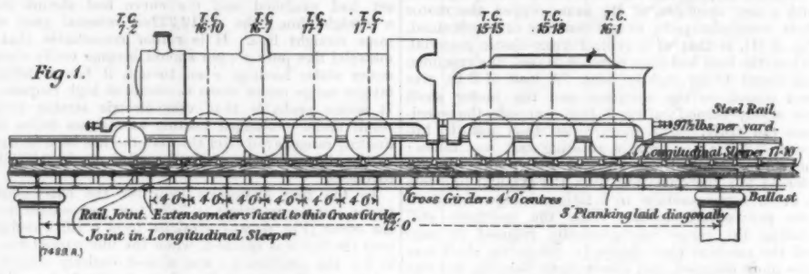


Fig. 1.

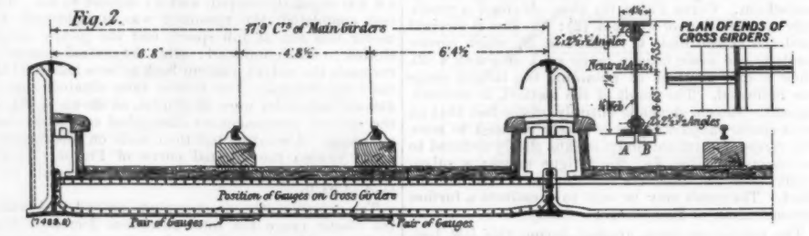


Fig. 2.

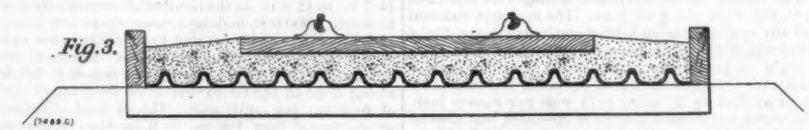


Fig. 3.

observers were sensible of unusual shock in this particular test, and in all probability this is a very high result.

There are 78 cross-girders in this bridge, and in only one case have loose rivets been found. Although the bridge is sixty-three years old and there are no traffic restrictions whatever, the cross-girders, so far as can be judged by ocular test, are as good as new.

Applying the proposed rules of the Ministry in the case of the cross-girder we should have to show 11 tons static stress and 122 per cent. impact allowance, making 24·42 tons, as being the total live load stress per square inch, an amount in excess of the breaking weight of the iron, whereas actually the greatest observed stress at speed was only 9 tons.

Considering this case further, although no records were taken with an engine standing on the bridge, we might predict a static recorded stress of two-thirds the maximum, say, 6 tons. To what are we to attribute the discrepancy between 6 tons and 11 tons? It will be conceded that there is little fixity at the ends. We are therefore driven to the conclusion that the expression $\frac{I}{Y}$ or "modulus"—or, shall we say, the extreme fibre stress method—does not accurately represent the capacity of the girder to resist transverse bending.

No explanation is here offered, although we have our own unconfirmed theories, and are of opinion that in view of the numbers of such girders in use and the money value involved in their replacement the most careful experiments should be undertaken by the railway companies jointly, advised by competent research men, with the idea of determining more accurately the resistance of beams of such form.

It has always seemed to us that the considered opinion of the late Sir B. Baker at the close of a discussion on this subject at the Institution of Civil Engineers, in 1900, is well worth re-reading when we find such stresses as 9 tons by actual measurement. So long as this is a fibre stress and the material ductile and the riveting sound, it is our experience that there is nothing to be feared. "Many engineers," said Sir Benjamin Baker, "would be astounded at the number of cases where, apart from initial stresses, good ductile wrought-iron had stood stresses from live and dead load of more than 10 tons per square inch for years without signs of distress. In early American bridgework heavy stresses were common. Thus, in a Railway Commissioner's Report of 1872, it had been mentioned that a 66-ft. bridge on the Erie Railway had broken down at last under an ordinary working stress of between 13 tons and 15 tons per square inch."

Additional evidence of what iron is capable of standing is obtained from the many bridges still in existence constructed of Barlow rails used as longitudinal beams. To give one of many cases known—refer to Fig. 3. This particular bridge is 12 ft. span, and traffic on the branch is restricted to engines which will not impose a bending moment greater than that produced by an equivalent uniformly distributed load of 2·82 tons per lineal foot of track at 12 ft. span. Assuming that nine Barlow rails carry the live load and the section modulus of a Barlow of reduced weight to be 8¼ in.³, the average stress would be 9·22 tons per square inch, of which 7·97 tons per square inch would be due to live load statically considered. The Ministry concludes that at 12 ft. span the provision for impact should be over 115 per cent. Thus they contemplate a momentary stress of about 17·2 tons per square inch.

It is not denied that occasionally higher stresses than 9·22 tons do occur, and in view of the performance of such bridges it is concluded that no anxiety need be felt, as a Barlow broken under traffic is almost unknown.

It might be mentioned here that the "report," alluding to the Pencoyd formula, says that "the tests appear to confirm that the formula does not provide sufficiently for short spans." The Pencoyd provision at 12 ft. span is 98 per cent. addition to the live load, which would contemplate a momentary stress of nearly 16 tons to the square inch on these Barlows, and we can only come to the conclusion that no such high stresses occur in the Barlows.

Another point in the report the maintenance engineer will venture to rebut is that no special concession need be made in the case of ballasted bridges. In effect it tells us that the cushion of ballast has no value as a shock absorber, which in our view is incorrect. More than one case could be quoted where the addition of ballast as a shock absorber has been the successful treatment for a bridge showing the first signs of disintegration.

Regarding the admitted reserve strength provided by our present methods of calculation, we are told that in view of certain other—and well known—accidental stresses, we should take no notice of the reserve mentioned; we must say again in answer to this that the old factor of safety has been proved to have made ample provision for all phenomena that can commonly affect small bridges including impact effect. We are of opinion that the maximum stresses recorded by the instrument may be taken as including the stresses alluded to and therefore it measured something more than "impact effect."

It is unfortunately a fact that most writers of books on bridge design feel impelled to announce to a waiting profession some discoveries of their own. Each discovery carries as a corollary additional weight of metal. There is to be noticed also nowadays a tendency to "refinement"—as it is called—of computations. The procedure is to calculate the primary stresses in the time-honoured fashion, then follows the investigation of secondary stresses, and of the inevitable metal to resist these locally, the old factor of safety being still retained. Another

modern tendency is to ignore the strength of steel beyond the elastic limit, relating the working stress to this limit by a reduced factor of safety. With regard to this tendency we have not yet heard of any specification which requires this limit to be the determining factor and the ultimate strength ignored. We are glad to see that the shipbuilders have recently made it quite clear that the elastic limit test is not practical politics. The idea behind such procedure is that as soon as the elastic limit is reached we are at the beginning of the end. Fortunately we know this is not so.

The tendency to give a formula for everything can scarcely be resisted. We can even get rules for the spacing of web stiffeners, some by professors and some by engineers. An idea of the value of these formulæ can be got by reference to Figs. 4 to 7, which give the principal features of the approach spans of a famous structure in question constant attention and examination is given to it. The result of recent extensometer measurements under the ordinary traffic of the day (Table II) will still further confirm the discrepancy between measured stresses and calculated stresses. Calculated stresses are not given for every type of engine passing over the structure, but the discrepancy can be seen by reference to the calculated stress from the 4-6-0 engine in comparison with the observed stress. The positions of the gauges are indicated on Figs. 4, 5 and 7, and a feature of the results is the consistent difference between the readings of the inner and outer gauge. This is constantly noted in extensometer measurements and is probably partly due to torsion, and partly to some local peculiarity.

The proposed regulations, combined with modern practice as regards stiffening, would result in such girders unscientific, but if science is reasoning from data, then consideration of the early bridges now in service is truly scientific. The theory of the masonry arch is imperfectly understood, but we don't hesitate to build arches because we are ill-informed on this point. Many such structures are unstable on the orthodox assumptions, or show pressures which should result in crushing.

The construction of what Americans call "pony" trusses is frequently condemned because "no one can say what stresses occur in unsupported top booms." Maintenance engineers know quite well that ample support is got in such bridges by the action of the web members. Probably secondary stresses are developed while the web members are exerting this restraint, but we do not commonly observe incipient failure as a result.

*Fig. 4. OUTSIDE ELEVATION OF GIRDER.*

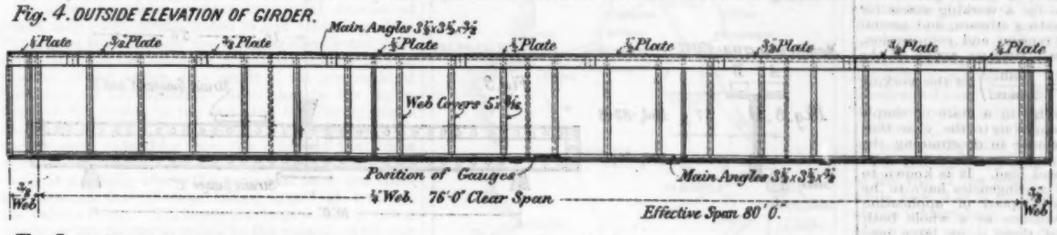



*Fig. 5. SECTIONAL PLAN OF BOTTOM FLANGE.*

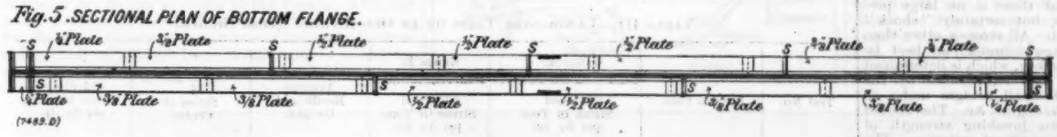



*Fig. 6. SECTION THRO' GIRDER.*

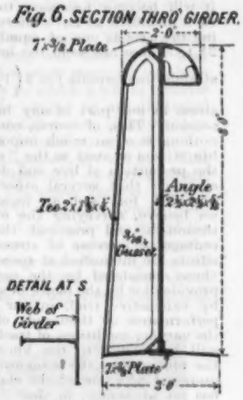



*Fig. 7.*

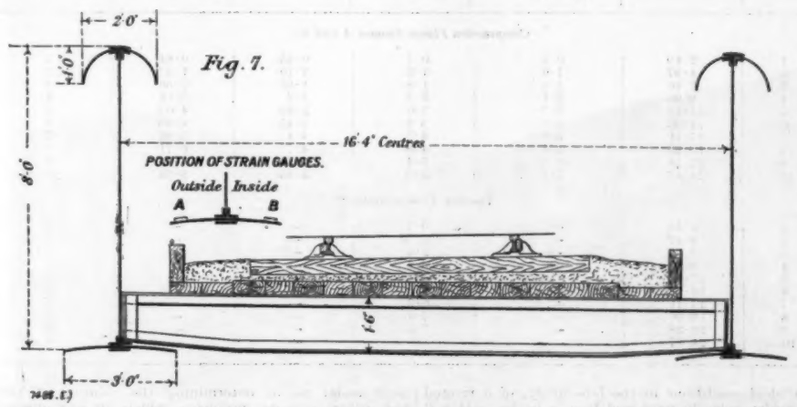



TABLE I.—EXTENSOMETER MEASUREMENTS ON OLD CROSS GIRDERS.

| Engine .. | 4-4-0. | | Tender 0-6-0. | | 4-6-0. | | 2-6-0. | | Tank 0-4-2. | | 4-4-0 Heading 2-6-0. | | 2-8-0. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gauge .. (See Fig. 2.) | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. | A. | B. |
| Test No.: | | | | | | | | | | | | | | |
| 1 | — | — | — | — | — | — | — | — | — | — | — | — | 9·0 | — |
| 2 | 2·8 | 5·0 | — | — | — | — | — | — | — | — | — | — | — | — |
| 3 | — | — | — | — | 2·4 | 6·5 | — | — | — | — | — | — | — | — |
| 4 | 6·5 | 5·4 | — | — | — | — | — | — | — | — | — | — | — | — |
| 5 | — | — | — | — | — | — | 6·6 | 5·9 | — | — | — | — | — | — |
| 6 | — | — | — | — | — | — | — | — | 2·6 | 3·7 | — | — | — | — |
| 7 | — | — | — | — | 2·2 | 6·4 | — | — | — | — | — | — | — | — |
| 8 | — | — | 2·2 | 3·7 | — | — | — | — | — | — | — | — | — | — |
| 9 | — | — | — | — | 4·2 | 8·1 | — | — | — | — | — | — | — | — |
| 10 | — | — | — | — | — | — | 4·7 | 6·1 | — | — | — | — | — | — |
| 11 | 7·4 | 4·8 | — | — | — | — | — | — | — | — | — | — | — | — |
| 12 | — | — | 2·0 | 3·6 | — | — | — | — | — | — | — | — | — | — |
| 13 | — | — | — | — | 2·8 | 6·3 | — | — | — | — | — | — | — | — |
| 14 | — | — | — | — | — | — | — | — | 1·8 | 4·2 | — | — | — | — |
| 15 | — | — | — | — | — | — | — | — | — | — | 6·5 | 6·4 | — | — |
| 16 | 4·8 | 6·2 | — | — | — | — | — | — | — | — | — | — | — | — |
| 17 | — | — | — | — | 3·6 | 6·8 | — | — | — | — | — | — | — | — |
| 18 | — | — | 4·4 | 3·8 | — | — | — | — | — | — | — | — | — | — |
| 19 | 5·0 | 5·2 | — | — | — | — | — | — | — | — | — | — | — | — |
| 20 | 6·1 | 4·7 | — | — | — | — | — | — | — | — | — | — | — | — |
| 21 | 6·5 | 3·0 | — | — | — | — | — | — | — | — | — | — | — | — |
| 22 | — | — | — | — | — | — | 7·1 | 2·3 | — | — | — | — | — | — |
| 23 | — | — | — | — | — | — | — | — | 6·0 | 4·2 | — | — | — | — |
| Average | 5·58 | 4·9 | 2·87 | 3·7 | 3·04 | 6·82 | 6·13 | 4·77 | 3·47 | 4·03 | 6·5 | 6·4 | 9·0 | — |

Calculated static stress due to passage of 2-8-0 engine—11 tons per square inch.

TABLE II.—*Extensometer Measurements on an Old Main Girder.*

| Engine .. | Rail Motor. | | 4-4-0. | | 2-6-0. | | 4-6-0. | |
|---|---|---|---|---|---|---|---|---|
| Gauge .. | A. | B. | A. | B. | A. | B. | A. | B. |
| Test No.: | | | | | | | | |
| 1 | — | — | — | — | — | — | 2·1 | 3·6 |
| 2 | 1·0 | 2·0 | — | — | — | — | — | — |
| 3 | 1·3 | 1·8 | — | — | — | — | — | — |
| 4 | — | — | — | — | not taken | 3·0 | — | — |
| 5 | 1·4 | 1·9 | — | — | — | — | — | — |
| 6 | 1·3 | 1·9 | — | — | — | — | — | — |
| 7 | — | — | — | — | 2·1 | 3·0 | — | — |
| 8 | — | — | — | — | 1·9 | 2·9 | — | — |
| 9 | 1·4 | 1·9 | — | — | — | — | — | — |
| 10 | — | — | — | — | 1·8 | 2·8 | — | — |
| 11 | — | — | — | — | 1·2 | 2·7 | — | — |
| 12 | — | — | 1·8 | 2·5 | — | — | — | — |
| 13 | 1·2 | 2·0 | — | — | — | — | — | — |
| 14 | — | — | — | — | 1·9 | 2·8 | — | — |
| 15 | — | — | — | — | 2·2 | 2·7 | — | — |
| 16 | 1·6 | 1·9 | — | — | — | — | — | — |
| 17 | — | — | — | — | 2·7 | 3·1 | — | — |
| 18 | — | — | 1·8 | 2·5 | — | — | — | — |
| 19 | — | — | — | — | 2·1 | 3·5 | — | — |
| 20 | — | — | 1·5 | 2·7 | — | — | — | — |
| 21 | — | — | — | — | — | — | 2·4 | 3·5 |
| 22 | — | — | — | — | 1·2 | 2·9 | — | — |
| 23 | — | — | — | — | 1·9 | 2·4 | — | — |
| 24 | — | — | — | — | 2·6 | 3·3 | — | — |
| 25 | — | — | — | — | 2·0 | 3·1 | — | — |
| 26 | — | — | — | — | 1·9 | 3·2 | — | — |
| 27 | — | — | — | — | 2·1 | 3·0 | — | — |
| 28 | — | — | — | — | 1·6 | 3·3 | — | — |
| 29 | — | — | 1·6 | 2·5 | — | — | — | — |
| 30 | — | — | — | — | 1·9 | 3·0 | — | — |
| 31 | — | — | 2·0 | 2·7 | — | — | — | — |
| 32 | — | — | — | — | 2·0 | 3·1 | — | — |
| Average .. | 1·31 | 1·91 | 1·74 | 2·58 | 1·95 | 3·04 | 2·25 | 3·55 |

Calculated static stress due to passage of 4-6-0 engine—4·49 tons per square inch.

bridge. Further details of these spans may be seen in "Humber" and probably elsewhere. It is quite well known that these original girders built in 1859 are in service at the moment, and an observer may see double-headed trains every day being carried by them without distortion.

It will be appreciated that owing to the age of the weighing 18 tons each, compared with the actual weight of 11 tons. Stiffeners would be fitted at about 8 ft. apart on each side of the web, and the web itself would be ⅜ in. thick for 60 ft., the remaining 20 ft. being ½ in. Instead of giving formulæ deduced from doubtful assumptions, reference might be given to actual details. There is a tendency towards calling such procedure

As matters stand to-day a majority of the railway engineers suggest that future bridgework shall be designed with an impact allowance on the "Pencoyd" basis until something better can be obtained, but they had suggested the use of the "Pencoyd" formula before the tests referred to were carried out, and in all probability before it was generally known that the formula was merely an inversion of a range-of-stress formula. We feel that it is unfortunate that the word "impact" became associated with the formula. Young engineers get the impression that, as a result of speed only, the effect of a load is double of that at rest. We have the opinion of Baker that a stress of 4 tons per square inch was a perfectly safe working stress for small girders in wrought iron. The same engineer in later specifications for steel structures gives 4½ tons for small members in steel. For many years the French Government permitted 5 tons in similar circumstances, and it is just possible that at this date with the accumulated results of extensometer testing and in view of the reserve of strength previously referred to that that distinguished engineer would have allowed this figure. In our own opinion this should give more than ample provision for all

contingencies,' and we therefore should fix 5 tons for "all live load." As regards dead load, provision has to be made for such contingencies as rolling, fabricating, temperature stresses, &c., and—remembering that the maximum stress in the Forth Bridge was fixed at 7½ tons—we consider that the "all dead load" stress might be fixed at that figure. For alternating stresses we are much impressed by evidence as to the effect of these in an account of the destruction of the cross-girders of an underbridge in four years, and we conclude that the principal factor was the employment of "distributing" girders, which produced alternating stresses in the cross-girders. This is the best practical confirmation we could have—if such were needed—of the Wöhler conclusions. We are assured that "a low unit strain" was adopted, and yet actual failure occurred.

Probably in the future we shall drop the practice of counterbracing the middle panels of braced girders and it will become necessary to fix a working stress for such members as have alternating stresses, and assuming the case as one of equal tension and compression, 2½ tons does not seem too low; thus we arrive at the straight line formula $f = 5\left(1 \pm \frac{\text{min.}}{2 \text{ max.}}\right)$ for the working stress in any part of any bridge in a state of simple tension. This, of course, commits us to the view that nothing is of so much importance in determining the life of iron or steel as the "range," or, as we may say, the proportion of live and dead load. It is known to everyone that several other contingencies have to be provided for, and as regards speed of application we believe, surveying the evidence as a whole both theoretical and practical, that there is no large percentage of increase of stress, but certainly "shock" effects are intensified at speed. All stresses other than those considered by the range formula can best be provided for by the factor of safety, which is determined by exhaustive trial, in our case represented by the performance of thousands of small bridges under all the varying conditions of track, engine, &c. This should still be related to the known breaking strength of the material as the soundest practical criterion. The proposed adoption of the elastic limit as the criterion has no advantage, in that "it completely ignores the reserve of strength possessed by a plastic material when subjected locally to stresses beyond the yield-point," and we know from Bauschinger that under work done on a bar the elastic limit is an extraordinarily varying quantity.

It is sometimes said that the increment of live load is much more convenient for calculating purposes than the varying stress method, as only in this way can the proper strength be obtained throughout the details, and that it enables the draughtsman the better to use certain tables previously worked out. We do not appreciate the point.

The formula we work to at the moment is

$$f = 4 \cdot 66\left(1 \pm \frac{\text{min.}}{2 \text{ max.}}\right)$$

the 4½ tons "all live load" stress having been fixed as keeping us within the 6½ tons limiting stress in the larger bridges, and, with a free hand we should, as previously suggested, increase this to 5 tons, as a result of our experience and the experiments of the last few years.

A table is compiled giving for all values of min ÷ max. the stresses in tension, compression, web shear, rivet shear and bearing pressure.

Tensile stress being taken as 100 the—

| | | | |
|---|---|---|---|
| Compressive stress is | ... | ... | 85 |
| Web shear is ... | ... | ... | 60 |
| Rivet shear is | ... | ... | 66 |
| Bearing pressure is | ... | | 200 |

In dealing with any member of a structure the draughtsman, having got the min. ÷ max., turns up the tables, writes down the five stresses and proceeds with the detailing. So far from there being any difficulty, we find that newcomers to the staff, used to other procedure, admit the all-round simplicity of our detailed rules.

In two particulars we find the "range of stress" method more rational than the "impact" method. First—as regards members subjected to alternations of stress, and second—the treatment of cross girders. In the case of the latter the "loaded length," the determining factor for impact increment, has to be arbitrarily assumed.

We are well aware that many engineers deny the applicability of the Wöhler law to bridgework, one apparently good argument being that the experiments were a continuous series of bendings with very small time intervals, whereas in a bridge the interval between trains is comparatively long, giving the material a chance of recovery.

Other engineers say that the law should not be applied because our working stresses do not exceed the elastic limit of the material. As regards those holding this opinion we would point out that reviewing all the processes the metal undergoes from rolling, straightening, &c., to its final incorporation in the finished structure, we feel certain that we must contemplate locally stresses beyond the limit mentioned, and the law becomes applicable immediately.

We have referred to an actual failure and to our belief in its value as evidence of the destructiveness of alternating stresses, and we prefer to incorporate the Wöhler law in our calculations for bridges.

It may possibly be urged that the differences in sectional areas required by Ministry of Transport rules, as against present-day practice are relatively small matters to large railway companies—that the underbridge work altogether is a fractional part of the total cost of a railway—and that the main point—standardisation—equality of strength on through routes—will be reached. We agree that—remembering our experiences in the transport of heavy loads during the war—a better general level of strength should be aimed at, and that a rule for the primary stresses in the principal parts should be agreed upon. We are by no means sure that matters of detail should be standardised because local circumstances frequently determine the details, and details will influence major features, and if the committee now sitting have this end in view we hope that they have asked for and obtained full particulars of the repair work found necessary in, say, the last ten years, and are making a special study of them. Standardisation tends to suppress a healthy rivalry amongst designers—therefore we hope it will not be overdone.

Returning to our principal point, viz., the apparent reserve of strength in girder work, in this connection it is interesting to note the results obtained from the testing, under ideal conditions in the laboratory, of a riveted cross-girder recently recovered from a bridge. It will be seen from the Figs. 8 and 9, and Table III, that judged by the measured stress on the extreme tensile fibre the beam is some 16 per cent. stronger than anticipated from calculation. The application of Baker's well-known rule to this girder predicted an enhanced strength of 16 per cent., and we may take it that under these ideal conditions the disparity between the calculated and observed stresses is far short of the disparity which would have been found if this girder had been re-incorporated in a bridge floor. Tests on a rolled steel beam were also made under the same conditions, and very similar results obtained, the disparity being about 13 per cent. To what then can we attribute the great difference between the measured stresses of a beam in the testing room and the same beam in a bridge? Is it the assistance given by adjacent members in the floor which tends sensibly to reduce the anticipated stress or is there anything in the interposition of springs, permanent way and ballast which prevents the full effect of the load being transmitted to the member? If there is anything in these speculations it might be that in a crawling test these effects are more fully developed, owing to time, than in a speed test, and this may be the reason for the low stresses recorded during crawling tests. If such be the case then the difference between the crawling tests and tests at speed represents something more than "impact effect," and consequently the allowance for the so-called "impact effect" should be materially less than represented in the report.

In view of the experiments that are still being conducted by the Indian Railway Bridge Committee and the probability of a demonstration that it is incorrect to provide for "impact effect" as a function of the total live load, but rather as a concentrated load on an axle or axles of the engine, it seems to us undesirable that any attempt should be made just now to propound even tentatively a rule which appears to be contrary to our experience of structures which are to-day successfully carrying live loads 30 per cent. to 40 per cent. in excess of those for which they were designed, and this, too, after upwards of sixty years' life.

So far as the work of the early engineers in wrought-iron is concerned we cannot observe any lack of appreciation of the problem as a whole; present-day engineers are fully alive to the importance of the effect of heavier loads and higher speeds, and can be relied on to construct their bridges with an ample margin of safety and to preserve the remarkable degree of immunity from disaster which has characterised the history of railway bridgework in this country.

In conclusion may we make a suggestion to the professional research workers present. The maintenance engineer has very little time at his disposal for such activities and would welcome collaboration. The perusal of many of your scientific papers gives us the feeling that you do not sufficiently appreciate the practical difficulties which confront us. In one direction for instance and arising out of the present-day performance of old structures, we know that there is a considerable reserve of strength in girder work; to what extent can and ought we to draw on this reserve? We suggest that you should be made welcome on our structures and by working with our staffs under ordinary conditions assist us in determining the solution of this and other cognate problems which in our opinion are of distinctly more importance than provision for "impact effect."

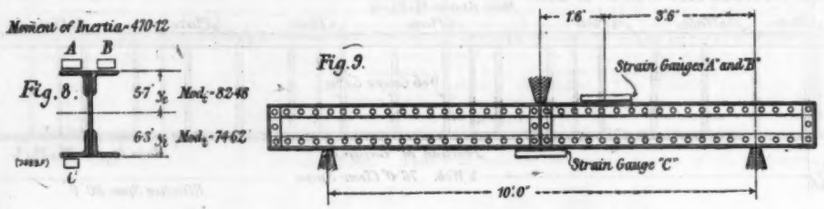



TABLE III.—LABORATORY TESTS ON AN OLD RIVETED CROSS GIRDER.

| Test No. | Load in Tons. | Gauge A. Observed Stress in Tons per Sq. In. | Gauge B. Observed Stress in Tons per Sq. In. | Average Reading of Gauges. | $\times \frac{5}{2\frac{1}{2}}$ for Stress at Centre. | Calculated Stress in Tons per Sq. In. |
|---|---|---|---|---|---|---|
| | | *Compression Flange Gauges A and B.* | | | | |
| 1 | 2·49 | 0·2 | 0·7 | 0·45 | 0·64 | 1 |
| 2 | 4·97 | 1·0 | 1·2 | 1·10 | 1·57 | 2 |
| 3 | 7·46 | 1·5 | 1·8 | 1·65 | 2·36 | 3 |
| 4 | 9·95 | 2·1 | 2·3 | 2·2 | 3·14 | 4 |
| 5 | 12·43 | 2·7 | 3·0 | 2·85 | 4·07 | 5 |
| 6 | 14·92 | 3·3 | 3·6 | 3·45 | 4·93 | 6 |
| 7 | 17·41 | 4·0 | 4·2 | 4·1 | 5·86 | 7 |
| 8 | 19·90 | 4·6 | 4·8 | 4·7 | 6·71 | 8 |
| 9 | 22·38 | 5·3 | 5·4 | 5·35 | 7·64 | 9 |
| 10 | 24·87 | 5·8 | 5·9 | 5·85 | 8·36 | 10 |
| | | *Tension Flange, Gauge C.* | | | | |
| 1 | 2·49 | — | 0·7 | — | — | 1 |
| 2 | 4·97 | — | 1·7 | — | — | 2 |
| 3 | 7·46 | — | 2·4 | — | — | 3 |
| 4 | 9·95 | — | 3·2 | — | — | 4 |
| 5 | 12·43 | — | 4·2 | — | — | 5 |
| 6 | 14·92 | — | 5·2 | — | — | 6 |
| 7 | 17·41 | — | 6·3 | — | — | 7 |
| 8 | 19·90 | — | 7·0 | — | — | 8 |
| 9 | 22·38 | — | 7·7 | — | — | 9 |
| 10 | 24·87 | — | 8·6 | — | — | 10 |

ABSORPTION BANDS IN GLASS.—Though the selective light absorptions shown by the compounds of the rare earths were observed by Bunsen himself and have been studied by several investigators since, the study has almost entirely been confined to liquid solutions and has not been extended to solid solutions. Both theoretically and practically such researches would manifestly have a high interest. The so-called didymium compounds generally obtained as mixtures of salts or oxides of neodymium praseodymium, samarium, lanthanum, cerium and other rare earths—in particular are distinguished by very striking absorption effects which are known to change with the physical and chemical conditions of the solutions; but they are also expensive, and for this reason very little has been done with didymium glasses. In 1918, E. Weidert, of the Sendlinger Optical Glass Works at Zehlendorf had sufficient didymium oxide at his disposal to prepare homogeneous glass melt in charges of 50 kg. to 75 kg. (100 lb. to 150 lb.) (*Zeitschrift für wissenschaftliche Photographie und Photochemie*, XXI, pages 254 to 264, 1922); the research remained incomplete for financial reasons. The absorption was studied by preparing glasses containing the same proportion of the oxide but differing in thickness, nitrate solutions serving as standards. Various parent glass melts were used, and it was found that they had different influences on the several absorption bands, wide and narrow, intense and faint, due to didymium. Some of these bands were widened and displaced—mostly to the red, but a few very strongly to the violet; other bands maintained the character and position they had, under different conditions. The intensities of the several portions in the bands were also affected to different degrees. As regards the influence of the parent glass, to which the rare earths had been added, it was observed that boric acid and, to a lesser degree, a strong proportion of lime made the bands wider and less distinct; the sharpest bands were observed with pure potash-lead glasses. This is of general interest to optical glass makers.

## HYDRO-ELECTRIC DEVELOPMENT IN CHILE.

SITUATED outside the great trade routes, Chile is comparatively little known except to people trading directly with the country, whose products are principally nitrate and copper. Occasionally during the summer months of the Southern Hemisphere a few others are attracted by the journey from Buenos Aires across the Argentine pampas and over the Cordillera of the Andes to Santiago or Valparaiso. Nevertheless the country well deserves attention, containing as it does, potentialities of very considerable importance. Among these must be placed its hydro-electric power, which has exceptional possibilities.

In other countries greater individual sources of power may exist, concentrated in one place or region. But in the case of Chile the power is distributed from north to south following all its eastern frontier, along the line of the Andes, as a result of the geographical formation of the country. Restricted to the region between the Andes on the east, and the Pacific Ocean on the west, the country consists of a comparatively narrow strip extending from the ridges of the Andes down to sea level. As the height of the mountain range is generally above the perpetual snow line there is a constant flow of water falling from high levels to the valleys below. Till lately this large source of power has been left to run to waste in the ocean. Although many persons in the past have obtained concessions for the development of water power from the Government, their object has been usually simply to sell the concession if the opportunity presented itself.

to develop the hydro-electric resources of the country. As a result of the preliminary studies of these engineers it was decided that the River Maipo and its affluent the Colorado, afforded the best prospects commercially, because they are situated in the central zone of the

the power for the electrification of the 180 km. of railway between Santiago and Valparaiso, to which we have already referred in these columns (see page 797, vol. cxii, of ENGINEERING). In course of time it is quite probable that this electrification will be extended to the main line running south, for it seems illogical to use steam when the hydraulic power is running waste within a few kilometres of the line.

Work in the River Colorado valley was commenced two years ago, and now is so well advanced that the inauguration of the new power station is expected to take place very shortly. The station has been built well inside the ravine of the river at a place called "Los Maitenes." From the intake a canal 8,000 m. long, with a carrying capacity of 11 cub. m. per second and a total loss of head of 7½ m., conducts the water to the Maitenes plant, which consists of three Pelton wheel generating units of 10,000 h.p. each. The available head is 180 m., and each unit will take at full load 5·5 cub. m. per second. A storage reservoir has been constructed near the forebay by which it will be possible to temporarily increase the output by an additional 14,000 h.p., thus giving a total power of 34,000 h.p. for peak loads, using two of the generating units.

The illustration, Fig. 2, subjoined, gives a good idea of the site of the power station and its surroundings, while Figs. 3 to 6, on page 300, show various features of the undertaking. Fig. 3 illustrates a typical piece of the open canal, while Fig. 4 shows the top end of the penstocks during construction. In several places the canal is taken through masonry tunnels along the hillside. Fig. 5 is a view of the power station and shows the three pipe lines from the forebay above-mentioned.

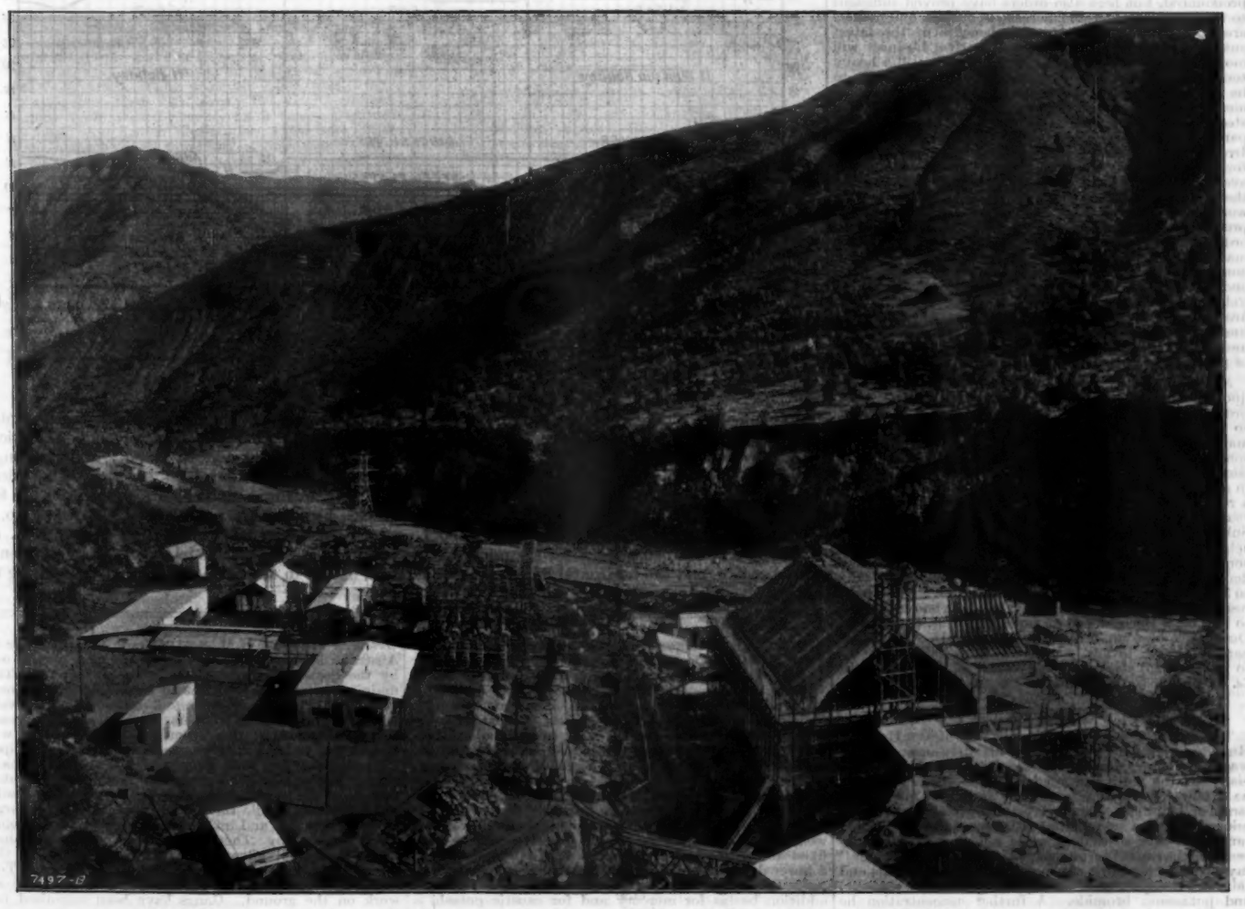



FIG. 2. POWER STATION AT LOS MAITENES IN THE RIVER COLORADO VALLEY.

About fifteen years ago a German company owning the electric tramway system of Santiago erected the first hydro-electric power station of any importance in the country, generating 12,000 h.p., and utilising for that purpose the waters of the River Maipo, which debouches from the mountains some 12 miles to the east of the capital.

More recently a Chilean company was formed through the efforts of the engineer, Don Juan Tonkin, in association with an American, Mr. Norman Rowe, country where the market for the power produced is far more favourable than elsewhere. At first the company formed was composed of Chilean shareholders, but three years ago Messrs. Pearson bought the tramway system of Santiago and soon after interested themselves in the hydro-electric projects. Subsequently a new company was formed with a capital of 8,250,000*l.*, to which the firm named has largely contributed.

The new company has already contracted to supply

The power station is of reinforced concrete and masonry, and the Pelton wheel units are arranged *en échelon*. Fig. 6 is a view of the outdoor transformer station with lightning arresters, &c,

Power will be generated at Maitenes at a voltage of 6,600, 50-cycle three-phase, which will be transformed up to 110,000 volts for transmission. The transmission line to Santiago will consist of two circuits of copper conductors, carried on double-circuit steel towers, with spans of 200 m. These towers are already

built as far as Santiago, where work has now been begun on the station. Later on the line will be continued to Valparaiso according to the map given in Fig. 1.

The plant above described is only a part of the scheme to be developed, as the company has acquired important rights in the river Maipo. When the whole project is realised the company will dispose of 200,000 h.p. in both rivers, which will place the system amongst the most important of its kind in the world.

## NOTES FROM SOUTH YORKSHIRE.

SHEFFIELD, Wednesday.

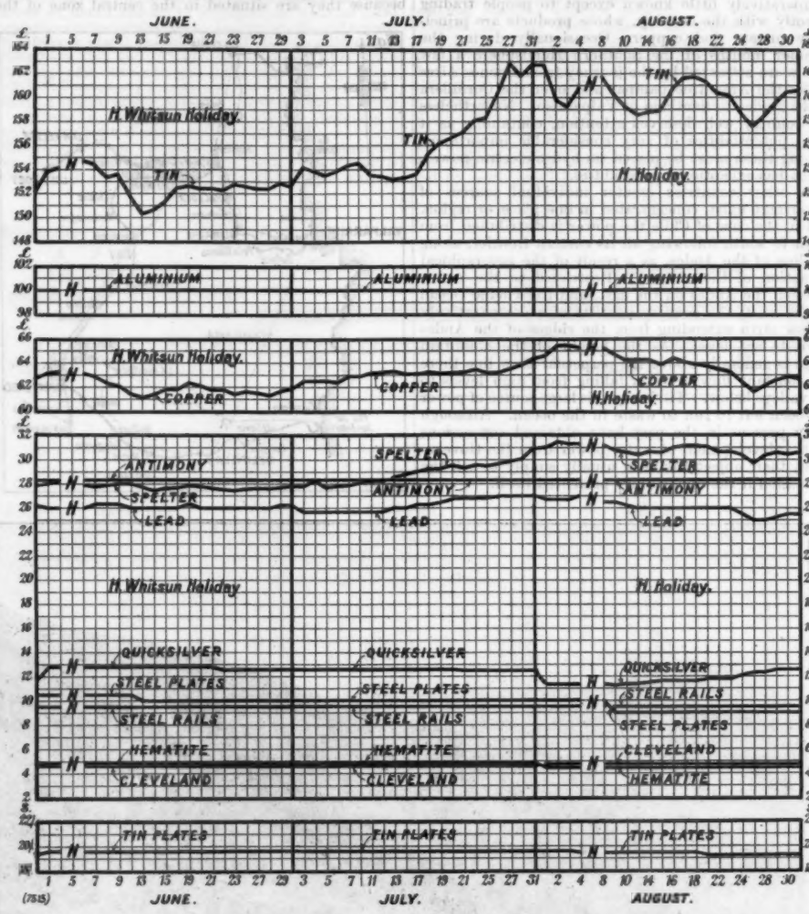
*Iron and Steel.*—The absence of armament work and the slump in shipbuilding orders are proving a very severe handicap on revival. Leading manufacturers endeavour to maintain an optimistic tone, but are confronted by the fact of Sheffield's exceptional position and see trying times ahead before normal conditions are restored. The current returns of unemployed are sufficient to dispel any high-flown hopes. In addition to 40,000 registered operatives for whom no work is available, there are some thousands of unregistered workers whose period of benefit has expired, or who for other reasons do not appear on the official return. A welcome feature is the closer co-operation of employers' and workers' organisations to stave off the worst effects of the prolonged depression, and to institute such conditions of employment as are calculated most quickly to attract new business. Both masters and men are making big sacrifices in this respect, realising that only by mutual agreement can current difficulties be surmounted with the minimum of damage to trading organisations. Mild steels are showing up distinctly better. The improvement in the crucible section is less pronounced, but here also orders have proved sufficient to warrant a considerable increase in output, and makers are hopeful that when the full benefits of the latest cuts in costs become generally operative, business will move more freely. At many works there is still a heavy tonnage of high-speed steel bought during the war to be worked off. Until this is absorbed the forward movement cannot show the best results. High quality tool steel occupies much the same position, though exports, particularly to America, are on a healthier scale. Irregular conditions prevail throughout the rolling mills, forges and foundries. Plant is not employed on the average above one-third of its normal capacity. Two of the largest engineering firms are widening the basis of a working arrangement so as to eliminate redundant processes and reduce production costs, which, on small orders, are exceptionally heavy. Good progress is being made on material and parts under the latest electrical contracts. The tool trades are more evenly employed, and are looking forward to increased bookings on Colonial and foreign account. India and South America are believed to offer solid possibilities. An expanding business is being done with Russia in implement parts and tools. Prices have been severely cut, but conditions of payment are being faithfully observed.

*South Yorkshire Coal Trade.*—Though there is no quotable change in official prices, many house coal producers have advanced the rates of best qualities 1*s.* to 2*s.* a ton. Forward business is moving more freely, and generally speaking pits are clear of stocks. Gas companies are taking increased deliveries now that consumption is on the up grade. The recent improvement in steam hards, chiefly on export account, has resulted in a reduction of short-time working at the pits, which are readily disposing of four to five days' output per week. Substantial inroads have been made into surpluses of cobbles and nuts. Only very small stocks remain. Coke continues firm under the influence of the American demand. Quotations:—Best branch handpicked, 36*s.* to 37*s.*; Barnsley best Silkstone, 33*s.* to 34*s.*; Derbyshire best brights, 23*s.* to 24*s.*; Derbyshire best house, 21*s.* 6*d.* to 22*s.* 6*d.*; Derbyshire best large nuts, 19*s.* to 21*s.* 6*d.*; Derbyshire best small nuts, 15*s.* to 16*s.* 6*d.*; Yorkshire hards, 21*s.* 6*d.* to 22*s.* 6*d*; Derbyshire hards, 19*s.* 6*d.* to 21*s.*; rough slacks, 8*s.* 6*d.* to 10*s.* 6*d.*; nutty slacks 7*s.* 6*d.* to 8*s.* 6*d.*; smalls, 3*s.* to 5*s.*

THE LATE PROFESSOR H. RUBENS.—Professor Heinrich Rubens, who died recently in his fifty-seventh year, was best known for his systematic optical work, especially in the infra red region of the spectrum which he extended very considerably by means of his "Restrahlen" method. He observed that certain crystallised minerals have a preferential reflection for very limited ranges of rays so that repeated reflections would concentrate the rays of certain wave lengths, the "remnant" rays being almost free of other rays. Such minerals and salts are fluospar, rock salt, sylvin (potassium chloride) and potassium bromide. A further concentration he effected, partly in conjunction with R. W. Wood, of Baltimore, with the aid of quartz lenses which, he found, give images of the different rays, passing through slits, at different distances. In these various researches on the dispersion and absorption of light, the thermopile, which bears his name, and his armour-clad galvanometer proved very useful. Together with Hagen he had previously worked with the Reichsanstald, on the reflective power of metals. These researches, as well as those on black body radiations, and his determinations of dielectric constants, were of great importance in connection with the theory of radiation and absorption, and supplied valuable material for Planck when he was advancing the quantum theory. Rubens was director of the Physical Institute of Berlin University and was respected as an exact worker and teacher.

## DIAGRAMS OF THREE MONTHS' FLUCTUATIONS IN PRICES OF METALS.

*(Specially Compiled from Official Reports of London Metal Markets.)*




NOTE.—In the diagrams the figures plotted for tin and copper are the official closing cash quotations of the London Metal Exchange for fine "foreign" and "standard" metal respectively. The prices shown for lead are for English metal, whilst those for spelter are for American metal. Middlesbrough prices are plotted for steel plates and rails, and also for hematite and Cleveland pig-iron. The prices given, in the case of steel plates are for ship, bridge and tank qualities, and those for steel rails are for heavy sections. The pig-iron prices are for the East Coast hematite and Cleveland iron, both of No. 1 quality and for home consumption. The price of tin-plates is per box of I.C. cokes f.o.b. at Welsh ports, but in all other cases the prices are per ton. Each vertical line in the diagram represents a market-day, and the horizontal lines represent 1*l.* each, except in the case of the diagram relating to tin-plates, where they represent 1*s.* each.

REAL AND APPARENT SPECIFIC GRAVITY OF COKE.—The determination of the density of coke is a matter both of some importance and difficulty, and none of the various methods—comprising optical tests—in use is very convenient. The volumetric apparatus which A. Schmolke described in *Glück Auf*, of August 12, is a fairly simple glass apparatus, easy to manipulate, but, we are afraid, not very expeditious. The idea is that the air in the pores of the coke is replaced by a heavy gas (carbon dioxide) which is subsequently absorbed by caustic potash; in another test the air is replaced by mercury, and the volumes of the coke and of the air expelled are determined. The sample of about 10 grammes weight is placed in a cylindrical vessel consisting of a fixed dome, to which a three-way cock is attached, and a lower detachable cup to receive the sample; the two parts fit together with a ground joint. There are, in addition basins for mercury and for caustic potash, a bulb provided with a graduated stem and tubes connecting these parts with the cup; two additional three-way cocks are required. The article from which we quote states that the carbon dioxide will replace the air in the coke in about 5 minutes, but that the impregnation is continued for another 10 minutes, and that the various figures check well with one another for the same sample, though different portions even of the same coke vary much as to porosity. But the actual time that a full determination would take is not stated, and with the porosity varying so much, elaborate determinations seem hardly worth the trouble.

THE MORWELL BROWN COAL SCHEME, AUSTRALIA.—The following particulars relating to the progress of this scheme have been forwarded to the Department of Overseas Trade by H.M. Senior Trade Commissioner in Australia. The whole of the works are being carried out by the State Electricity Commission of Victoria. The main power station, which is to be situated at the new township of Yallourn, about 5 miles from Morwell, and is expected to be in operation in about two years time, will have an initial capacity of 50,000 kw. and will contain five 12,500 kw. turbo-generators. All the principal contracts for the plant and machinery for the main power station have been placed, and a considerable portion of the transformers, switchgear, &c., has already been delivered, while the manufacture of the five large turbo-alternators and of the condensing plant being manufactured by Thompson and Co., Castlemaine, Victoria, is well advanced. The greater part of the preparatory work of the site has been completed. The contractors for the steel for the power station are at work on the ground. Gangs have been organised for the erection of the transmission line over a distance of 112 miles. The erection of the auxiliary station at Newport is proceeding satisfactorily and justifies the anticipation that it will be in operation by May, 1923, as originally intended. In regard to the coal-winning operations, the removal of overburden has already begun, and it is expected that the winning of coal will be commenced by the end of this year. A considerable portion of the briquetting machinery has arrived. The Government have authorised the erection of a model township at Yallourn, and this is being put in hand with all speed. The township scheme, which is estimated to cost 224,000*l.*, provides, in its first stages, for accommodation for the Commission's employees by the erection of 200 tenements, but the final scheme makes provision for a population of 3,000.

## NOTES FROM CLEVELAND AND THE NORTHERN COUNTIES.

MIDDLESBROUGH, Wednesday.

*The Cleveland Iron Trade.*—Substantial buying of the better qualities of Cleveland pig iron for shipment to the United States has been followed by shortage of those commodities, with the result that prices have risen half-a-crown a ton. Stocks have been largely disposed of and f.o.t. makers' works or f.o.b. Tees quotations now stand: No. 1 and siliceous iron, 97*s.* 6*d.*; No. 3 G.M.B., 90*s.*; and No. 4 foundry, 87*s.* 6*d.* No. 4 forge is fairly plentiful and is still obtainable at 82*s.* 6*d.* to 85*s.* There is now practically no mottled and white iron.

*Hematite.*—Though hematite has not moved up with Cleveland, and has in fact been sold at below the current price of No. 3, as low as 89*s.* having been accepted, for mixed No. 1 the position is stronger, and advance is looked for. The general market quotation for Nos. 1, 2 and 3 is in the neighbourhood of 90*s.* both for home consumption, and for shipment abroad, and some makers ask up to 91*s.* 6*d.*

*Foreign Ore.*—Inactivity still characterises foreign ore, but dealers anticipate some movement in the near future. Best rubio is fully 24*s.* 6*d.* c.i.f. Tees, and good Mediterranean ores are round about 23*s.* c.i.f. Tees.

*Manufactured Iron and Steel.*—Some improvement in demand for finished iron and steel is noticeable, but business is checked by uncertainty of prices. Values are a matter of individual negotiation and are thus difficult to fix definitely. For local delivery common iron bars and iron angles are 11*l.*; iron ship rivets, 12*l.* 17*s.* 6*d.*; black sheets, 12*l.*; galvanised corrugated sheets (No. 24 gauge, in bundles), 16*l.* 10*s.*; steel boiler plates 12*l.* 10*s.*; steel ship, bridge, and tank plates, 9*l.*; steel angles, 8*l.* 10*s.*; steel joists, 9*l.*; and heavy sections of steel rails, 9*l.* 10*s.*

*Shipments of Iron and Steel.*—August shipments of iron and steel from the Tees last month including 2,613 tons of pig iron cleared at Skinningrove, amounted to 70,093 tons, composed of 37,972 tons of pig iron, 5,574 tons of manufactured iron, and 26,547 tons of steel. The United States was the largest buyer of pig iron, importing 9,862 tons, whilst Wales received 5,000 tons; Italy 4,023 tons; Scotland, 3,150 tons; Belgium, 3,096 tons; Germany, 2,680 tons; France, 1,420 tons; Denmark, 1,276 tons; and British West Indies, 1,000 tons. India was again the heaviest purchaser of both manufactured iron and steel, taking 2,410 tons of the former, and 8,419 tons of the latter. Other principal customers for steel were, Victoria, 4,144 tons; Japan, 1,733 tons; and the Straits Settlement, 1,608 tons.

*Imports of Iron and Steel to the Tees.*—Tees Conservancy Commission returns show that for the ten months ending August last 34,268 tons of pig iron arrived in the Tees from Holland, Belgium, France, Norway, Sweden, Germany, and coastwise, as compared with 37,462 tons for the same time a year ago, and 312 tons for the corresponding pre-war period 1913–14. Sheets, bars, billets, blooms, and slabs imported in the past ten months from the countries named reached 47,197 tons as against 24,344 tons a year ago, and 33,646 tons in the months of 1913–14. Plates, angles, rails, sheets, and joists brought to the Tees in the past ten months amounted to 8,528 tons, against 19,309 tons a year ago, and 19,441 tons in the ten months 1913–14.

## NOTES FROM THE NORTH.

GLASGOW, Wednesday.

*Scottish Steel Trade.*—The past week has brought out little or nothing in the way of a change in the state of the steel trade of Scotland. Buying continues to be very carefully indulged in and consumers are still very reluctant to commit themselves at the present time, being convinced that the waiting policy will pay them in the long run. The foreign inquiry is fairly good and a limited amount of business is passing, but expansion in that direction is rather slow. Structural sections still form the principal item of dealing in the home trade, with ship plates a very bad second. Prices are nominally without change, but when any decent lines are on offer shading of quotations takes place. In the black sheet trade thin gauges continue to be in good demand on export account, but the thicker gauges are not much sought after either for home use or for shipment. The following may be taken as the current prices for home delivery:—Boiler plates, 12*l.* 10*s.* per ton; ship plates, 9*l.* per ton; sections, 8*l.* 15*s.* per ton; and sheets, ¼ in., 10*l.* 5*s.* per ton, all delivered Glasgow stations.

*Malleable Iron Trade.*—The demand for bar iron is still very poor and there has been little movement over the week. The home consumers are not purchasing much at present, and business is chiefly confined to export lots and even they do not make up a very heavy tonnage. Prices are unchanged with "crown" bars at 10*l.* 10*s.* per ton delivered Glasgow stations.

*Scottish Pig Iron Trade.*—The main feature in the pig-iron trade of Scotland is the improvement which has been very noticeable of late in the amount going abroad. The tonnage available for export is of course very limited at the present time with so few furnaces in blast, but from the current inquiry it would almost seem as if the output would require to be increased very soon. American buyers are taking up a fair amount, but just how long that will last is a doubtful point. Foundry iron is the main quality desired at present as hematite is little required on account of the dull state of the steel trade. For the week ending last Saturday, the total amount of pig-iron shipped from Glasgow harbour was 2,208 tons, 2,120 tons of which went abroad, whereas for the corresponding week last year the figures were 35 tons shipped, of which 25 tons went foreign. Prices are firm and are as follow:—Hematite iron, 5*l.* 7*s.* 6*d.* per ton, delivered at the steel works; foundry iron, No. 1, 5*l.* 5*s.* per ton; and No. 3, 5*l.* per ton, both on trucks at makers' works.

*Scottish Shipbuilding.*—The shipbuilding output for the month of August was considerably above the average monthly output for the year and amounted to 65,225 tons as against 59,524 tons for January, which was the previous best. The activity of the industry cannot, however, be measured by the tonnage launched because of the fact that there are few contracts on hand to take the place of those vessels now put into the water. The outstanding fact is that each month's output recently has meant a decrease in employment at the yards, and until cost of construction is reduced shipowners will not place orders and things must go from bad to worse. Much interest is being taken in the fateful meeting at Edinburgh next Monday when a round-table conference will take place between the employers and the representatives of the workers of the various shipbuilding unions. Should an agreement be arrived at to reduce still further the men's emoluments there is a prospect of several more contracts being placed on the Clyde at any rate, but if no arrangement is arrived at the outlook for the industry will be blacker than ever. The few orders recently placed do not amount to very much in comparison with what is possible, and only a wholesale placing of new business can save Scottish shipbuilding from a period of depression such as has not been experienced for a number of years back. The following are the figures for the output of the past month and for the year to date:—

| | August. | | Eight Months. | |
|---|---|---|---|---|
| | Vessels. | Tons. | Vessels. | Tons. |
| The Clyde ... ... | 17 | 53,849 | 90 | 254,303 |
| The Forth ... ... | — | — | 4 | 10,093 |
| The Tay ... ... | 2 | 11,350 | 6 | 21,150 |
| The Dee and Moray Firth ... ... | 1 | 26 | 8 | 163 |
| Totals ... | 20 | 65,225 | 108 | 285,790 |

## NOTES FROM THE SOUTH-WEST.

CARDIFF, Wednesday.

*July Coal Trade Results.*—In July the output of coal in South Wales was 330,000 tons more than in June. The cost of production was decreased by 9*d.* per ton, of which wages showed a reduction of 5*d.* and "other costs" 4*d.* Selling prices were also reduced by 5*d.* After allowing for the cost of standard wages, other costs and the owners' standard profits of 17 per cent., there was a surplus in July of 6,566*l.* which was applied to the reduction of the actual deficit shown in June of 56,480*l.*, leaving a deficit of 49,914*l.* to be met out of any subsequent surplus. The workmen, are, however, entitled to a minimum wage of 28 per cent. above the 1915 standard, and this can only be met by the owners sacrificing their standard profits of 302,721*l.*, plus an additional 46,989*l.*, so that the total amount sacrificed by the owners in paying the minimum wage is 349,710*l.* Though huge orders were placed for Welsh coal by America in July, the benefit of this business is not reflected in the July returns, for it was not until August that actual shipments were made on an extensive scale. Since November last the owners have sacrificed something like 2,334,000*l.*, the whole of which sum is irrecoverable.

*The Coal Trade.*—With the settlement of the American miners' strike the demand for Welsh coal has been less pressing. But so long as the railway strike continues it is expected that the United States will continue to require supplies of foreign coal, though in a less degree than has been the case during the last couple of months. Canada, however, is still placing orders for Welsh coal, especially dry large and anthracite. Shipments are still actively proceeding and a large quantity is to be exported. Last week exports of coal from South Wales reached the highest level touched since the war. In all, 606,400 tons were shipped, which is equal to a rate of more than 30½ million tons per annum and compares with just under 30 million tons in the record year of 1913. Of last week's shipments 185,700 tons, or 30 per cent. of the total, went to the United States and Canada, which brings the total to date to 621,200 tons. Charterings on the freight market reached 148,500 tons, making a total to date of 1,414,000 tons, so there is at least another 800,000 tons of Welsh coal to be shipped to the States and Canada. At the Customs a further 28 vessels totalling 78,596 net tons were "entered outwards," which brings the total to 176 steamers aggregating 538,000 net tons, representing a cargo carrying capacity of over 1,000,000 tons. In addition a couple of steamers have also been chartered to carry patent fuel from Swansea to Canada. Generally, prices on the coal market are easier. Anthracites however remain scarce, with cobbles commanding 75*s.* and Big Vein large 65*s.*, while dry large is also firm at 30*s.* In steams, however, best Admiralty large commands no more than 29*s.* 6*d.*, seconds 28*s.*, and Monmouthshires from 26*s.* to 27*s.* 6*d.* Best steam smalls are from 18*s.* 6*d.* to 19*s.* 6*d.*, with ordinaries round 17*s.* 6*d.* and inferiors from 14*s.* to 17*s.*

*Iron and Steel.*—Exports of iron and steel goods last week amounted to only 2,703 tons, the smallest quantity reported as shipped in any week of this year. Of the total, 159 tons comprised black plates, a reduction of 532 tons when compared with the previous week; 1,002 tons tinplates, a decrease of 2,674 tons; 565 tons galvanised sheets, a decline of 895 tons; but iron and steel at 977 tons showed an increase of 379½ tons. The Continental demand for tinplates has been restricted mainly on account of the adverse movement in exchange rates.

## NOTICE OF MEETING.

THE INSTITUTE OF MARINE ENGINEERS INCORPORATED.—Tuesday, September 12, at 6.30 p.m., at 85-88, The Minories, Tower Hill, E. 1. Presidential Address by Engineer Vice-Admiral Sir George G. Goodwin, K.C.B., LL.D.

CORROSION OF CHROMIUM STEELS: ERRATUM.—In a paragraph on this subject published on page 275 of our last issue reference was made to an article on the "Resistance and Corrosion of various Types of Chromium Steels" by Messrs. H. S. Rawdon and I. Krynitsky, which it was stated was published in the number of *Chemical and Metallurgical Engineering* of July 22 last, whereas the date given should have been July 26. The article referred to will be found on page 171 of the issue of the last named date.

DEATH OF MR. CHARLES GODFREY PHILLIPS.—We much regret to learn of the death on Sunday last at Llandrindod of Mr. Charles Godfrey Phillips, of the Emlyn Engineering Works and Foundry, Newport, Mon. The deceased gentleman who was subject to attacks of giddiness fell through a window of his hotel, fracturing his skull. He was 48 years of age, and was the son of the late Mr. Charles D. Phillips, the founder of the Emlyn Engineering Works. Of this establishment Mr. Phillips became joint manager in 1912, and retained this position up till a few months ago. During the war he served as Captain with the second line of the 4th Welsh R.F.A. Territorials, which were raised in Monmouthshire.

THE BRITISH CAST IRON RESEARCH ASSOCIATION.—The Director of Research states that during September members have sought advice on problems connected with cupola design and operation, mixtures for heavy cylinders, intricate chilled iron and malleable castings, irregularity in pig irons and scrap, alloy cast irons for castings subject to repeated and continuous heating, sand mixtures for light castings, scaling defects in annealed cast iron articles, &c. The difficulties arising from defective design, causing shrinkage and porosity cracks, have again been signally prominent in a number of problems submitted by members. The erosion of vessels for heating and melting non-ferrous metals is occupying the serious attention of the Association, and aid has been sought in suggesting suitable mixtures for this service. Work is now proceeding in the more serious researches on motor car cylinders, moulding sands, refractories, draws and shrinkage. Interim reports on the progress of these important researches have been prepared for early issue to the members.

THE INSTITUTION OF CHEMICAL ENGINEERS.—At the twelfth meeting of the provisional committee of this Institution held on Wednesday, August 2, 1922, at 166, Piccadilly, London, Sir Arthur Duckham, K.C.B., M.Inst.C.E., presiding, it was reported by the solicitor that the registration by the Board of Trade was still delayed. The suggestions of the Institute of Chemistry were agreed to, viz., that the definition of chemical engineering should be omitted, and that a clause should be inserted by which the Institution claim no right to prescribe courses of study or to hold examinations whereby qualifications or authority to practice or to use any distinctive title can or may be conferred in respect of the practice as such of analytical or technical chemists (other than chemical engineers) or of teachers of chemistry. The committee were unanimously opposed to changing the title of the institution. A balance sheet and revenue account was submitted by the honorary treasurer, showing a surplus balance of 225*l.* 6*s.* 8*d.* The honorary secretary reported that over 100 completed application forms for membership had already been received. It was agreed that the question of membership must be held in abeyance until negotiations were completed by the Board of Trade, which it was hoped would be in about six weeks from the date of this meeting.

INSTITUTE OF MARINE ENGINEERS INCORPORATED.—The session will be reopened on Tuesday, September 12, by Sir George G. Goodwin, who is arranging to deliver his Presidential Address on that evening. A programme can be obtained from the Institute, 85, The Minories, Tower Hill. It is as follows: Tuesday, September 26, film illustrating the works of Messrs. Vickers, Limited; Tuesday, October 10, "Conditions to Get High Economy from Oil Fuel," by Alberto Keenes, Member; Tuesday, October 24, views illustrating industrial works, Messrs. Bruce, Peebles; Friday, November 3, annual dinner, Hotel Cecil; Tuesday, November 14, "The Evolution of the Nobel Diesel Engine," by G. J. Steinheil, B.Sc., Member; Tuesday, December 5, "Marine Diesel Engines," by A. J. Brown; Tuesday, December 19, film illustrating the works of Messrs. Hadfields, Limited; Tuesday, January 9, "Gas Engines and Gas Producer Plants," by Hugh Campbell; Tuesday, January 23, film illustrating the works of Messrs. William Beardmore and Co., Limited; Tuesday, February 13, "Internal Combustion and Economy," by T. D. Madsen; Tuesday, March 13, "The Development of the Air Pump for High Vacuum," by W. A. Dexter. Meetings of the Institute of Metals are to be held in the Institute of Marine Engineers' Lecture Hall on Thursday evenings at 8, on October 12, December 14, January 11, February 8, March 8 and April 12, and the Institution of British Foundrymen will also hold meetings on the first Thursday of each month at 8. All members are invited to attend these meetings, the subjects for which are not yet decided, but will be announced later.

# HYDRO-ELECTRIC DEVELOPMENT IN CHILE.

(*For Description, see Page* 297.)

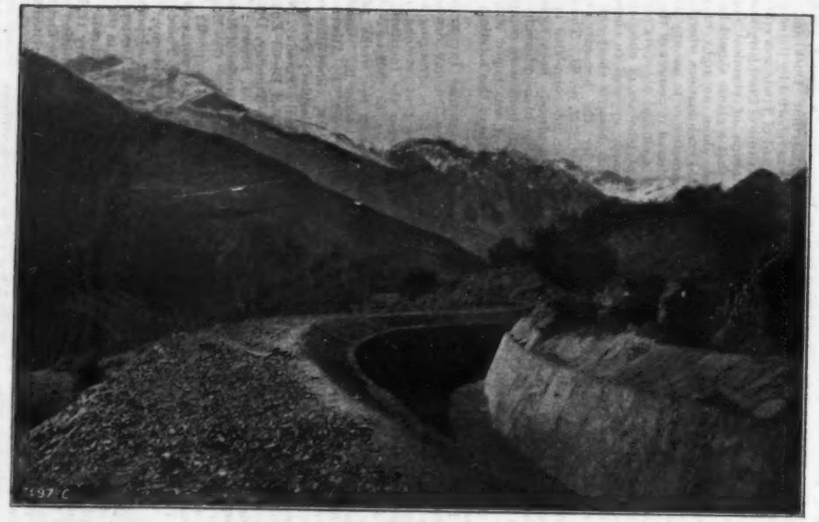


Fig. 3. Open Canal above the Los Maitenes Power Station.

Fig. 4. The Penstocks during Construction.

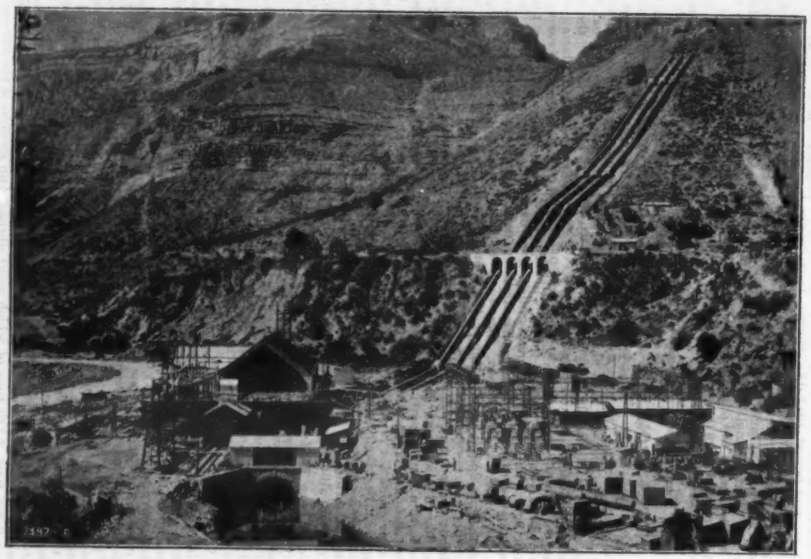


Fig. 5. The Maitenes Power Station and Pipe Lines.

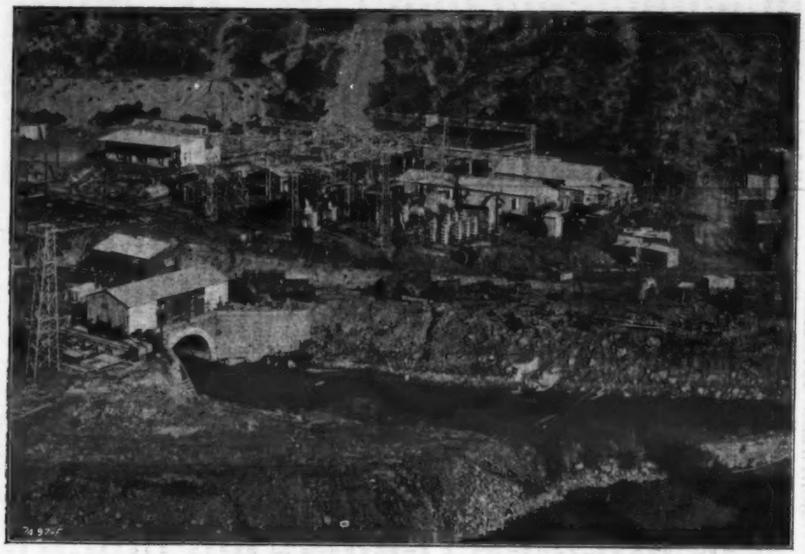


Fig. 6. Out-door Transformers, and Lightning Arresters.

# THE RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.

(For Description, see Page 287.)

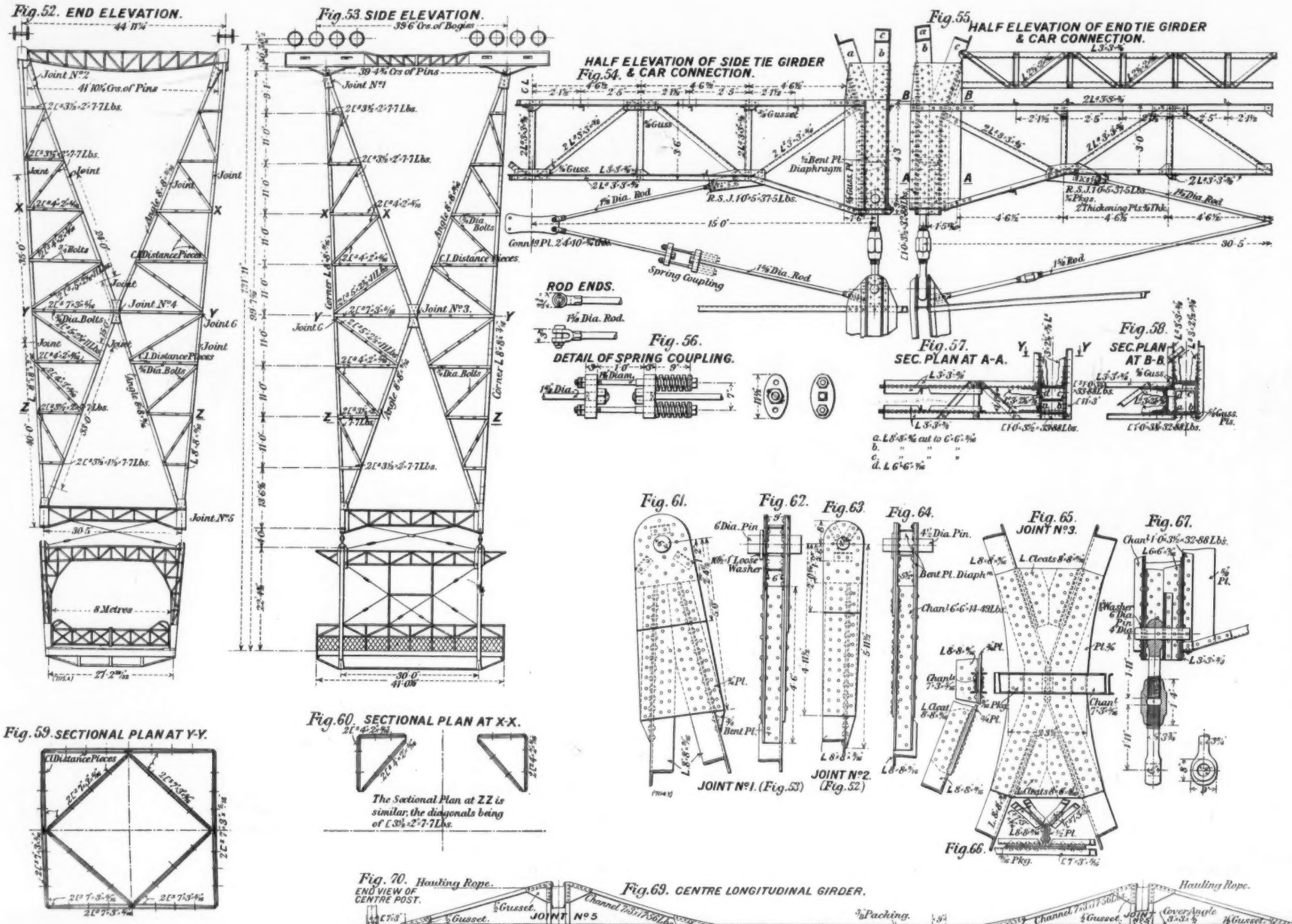


Fig. 52. END ELEVATION.
Fig. 53. SIDE ELEVATION.
Fig. 54. HALF ELEVATION OF SIDE TIE GIRDER & CAR CONNECTION.
Fig. 55. HALF ELEVATION OF END TIE GIRDER & CAR CONNECTION.
ROD ENDS.
Fig. 56. DETAIL OF SPRING COUPLING.
Fig. 57. SEC. PLAN AT A-A.
Fig. 58. SEC. PLAN AT B-B.
Fig. 59. SECTIONAL PLAN AT Y-Y.
Fig. 60. SECTIONAL PLAN AT X-X.
The Sectional Plan at Z Z is similar, the diagonals being of L 3½ × 2½ × 7/16 Lbs.
Fig. 61.
Fig. 62.
Fig. 63.
Fig. 64.
Fig. 65. JOINT No 3.
Fig. 66.
Fig. 67.
JOINT No 1. (Fig. 53)
JOINT No 2. (Fig. 52)
Fig. 68. KEY PLAN OF TROLLEY FRAME
Fig. 69. CENTRE LONGITUDINAL GIRDER.
Fig. 70. END VIEW OF CENTRE POST.
Hauling Rope.
JOINT No 5
JOINT No 4

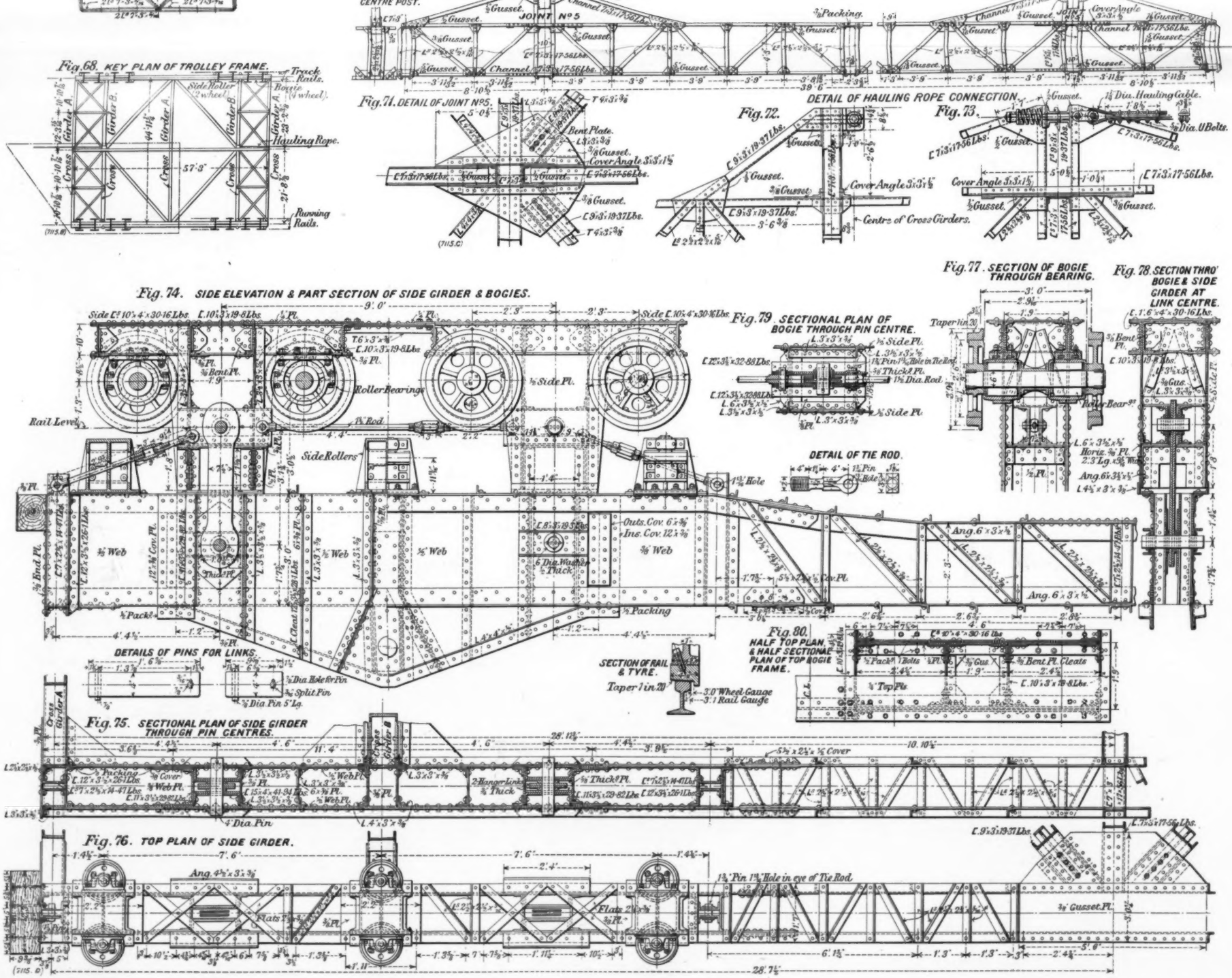


Fig. 68. KEY PLAN OF TROLLEY FRAME.
Track Rails.
Bogie (4 wheel).
Side Roller (2 wheel).
Girder A.
Girder B.
Cross
Hauling Rope.
Running Rails.
Fig. 71. DETAIL OF JOINT No 5.
JOINT No 5
Bent Plate.
Cover Angle
Gusset.
Fig. 72.
DETAIL OF HAULING ROPE CONNECTION.
Centre of Cross Girders.
Fig. 73.
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Fig. 74. SIDE ELEVATION & PART SECTION OF SIDE GIRDER & BOGIES.
Roller Bearings
Side Rollers
Rail Level
Fig. 75. SECTIONAL PLAN OF SIDE GIRDER THROUGH PIN CENTRES.
Fig. 76. TOP PLAN OF SIDE GIRDER.
Fig. 77. SECTION OF BOGIE THROUGH BEARING.
Fig. 78. SECTION THRO' BOGIE & SIDE GIRDER AT LINK CENTRE.
Fig. 79. SECTIONAL PLAN OF BOGIE THROUGH PIN CENTRE.
DETAIL OF TIE ROD.
DETAILS OF PINS FOR LINKS.
SECTION OF RAIL & TYRE.
Taper 1 in 20
3'0" Wheel Gauge
3'1 Rail Gauge
Fig. 80. HALF TOP PLAN & HALF SECTIONAL PLAN OF TOP BOGIE FRAME.

# ENGINEERING.

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*One Two-Page Plate.—DETAILS OF THE RIACHUELO TRANSPORTER BRIDGE, BUENOS AIRES.*



# ENGINEERING.

*FRIDAY, SEPTEMBER* 8, 1922.


## INDUSTRIAL NEGOTIATIONS AND AGREEMENTS.

WE have received from the Trades Union Congress and the Labour Party an interesting pamphlet containing the results of a study by their Joint Research Department of Industrial Negotiations and Agreements. It gives a general outline of the various means and methods by which conditions of labour and pay are arranged directly or indirectly by trade unions and associations of employers in Great Britain, but there is some evidence in the introduction and in the "Foreword" by Mr. Clynes—though not in the pamphlet itself—of an attempt to combine the results of research with trade union advertisements. "We all have plans and projects," says the writer of the introduction, "that will have to wait until times are normal once more before we can hope to see them realised, but here is a task which can be undertaken now; we can, at any rate, make our own organisation a better instrument for carrying out the policy to which we are committed." And Mr. Clynes concludes his foreword by asking "Are there still men who are ready to pocket all that a union can get for them and keep in their pockets the little they should pay to help the union to get terms which all men are eager to share?" Mr. Clynes is justly proud of the work which trade unions have done in negotiating industrial agreements with employers, but in his reference to "agreements requiring employers to observe stated conditions of labour and pay for their workers" as a new type of contract, he scarcely does justice to the voluntary nature—on both sides—of these agreements. If we are to speak of agreements requiring employers to observe stated conditions of labour and pay, we may as well speak of agreements requiring employees to accept, or at least acquiesce in, these conditions.

There is, indeed, a good deal of popular misapprehension of the legal effect of agreements between trade unions and employers' associations. Where such an agreement is made, fixing the rates of wages for a given industry or branch of industry, it is sometimes assumed that it becomes automatically part of the contract of employment between each member of the employers' association and each member of the trade union whom he happens to employ, so that if he fails or refuses to pay these rates of wages he can be compelled to do so by the Courts. This, however, is not necessarily the case. No doubt an employers' association might be empowered by its constitution to bind its members in this way, though difficult legal questions might arise under trade union law as to the enforceability of such an agreement, and it would be difficult to imagine what the corresponding obligation on the members of the trade union would be; but as a rule these agreements amount to no more than an arrangement or understanding that each member of the employers' association will be expected to pay the wages and observe the conditions agreed on, and each member of the union will be expected to accept and acquiesce in them. If an employer fails to give effect to the agreement, the union's remedy is to complain to his association so that any necessary pressure may be put upon him by the executive; and if the men strike for higher pay or better conditions than those provided for in the agreement, the union executive are expected, so long as the agreement remains in force, not only to refrain from supporting the strike, but to make every effort to get the men to go back to work. It is to the credit of masters' and men's associations that in the great majority of cases, they loyally carry out their agreements in this way.

The recent case before the magistrates at Newcastle-upon-Tyne, arising out of the dispute in the printing trade, furnishes a sample of the questions with which the Courts have to deal when the parties to industrial agreements invoke their aid for their enforcement. The executives of the men's and the employers' societies agreed that the dispute should be referred to the Industrial Court as arbitrators. The Court's award was for an immediate reduction in wages. By the custom of the printing trade, the men's engagements are terminable on a fortnight's notice on either side, and it follows that in the ordinary case a fortnight's notice should be given of any alteration in the rates of wages. The proprietors of a leading newspaper in Newcastle reduced the wages of their employees in accordance with the Industrial Court's award without giving a fortnight's notice, and the men went out on strike. The proprietors sued them for damages, and the question at issue was whether it was the masters or the men who had broken the men's contracts of employment. The magistrates held that the executive of the men's union had power by its constitution to agree to arbitration, that the masters were entitled to reduce the wages in accordance with the award, and that the men had broken their contracts and had become liable in damages by going on strike without first giving a fortnight's notice. We do not know on what evidence the decision was based, but although the men's action in refusing to abide by the award cannot be commended—it is but just to mention that the result of a ballot of the union was against acceptance of the award—we confess to being not a little surprised at the magistrates' decision, and shall be interested to see whether it is upheld on appeal.

Our view of the effect of industrial agreements of the kind under discussion is supported by the pamphlet in its division of them into legally enforceable agreements and non-enforceable agreements. The former class rely for their enforceability on statutory sanction such as that of the Trade Boards Acts. The pamphlet gives a complete list of the trade boards now in operation and much useful information as to conciliation and arbitration boards, joint industrial councils and the existing arrangements in different trades and industries for discussion and negotiation between the employers' and the workers' representatives. It is a pity, however, that it is disfigured in a few places by such statements as "The State merely keeps the ring when Labour is weak, but it intervenes to deliver the knock-out blow on behalf of the employer when Labour is strong," or "The resulting publicity [of the proceedings of the Coal Industry Commission of 1919] provided the most damaging attack ever made in this country on any body of employers." Statements of this kind, we are glad to say, are not taken seriously by the general public, but

nevertheless a little judicious editing would decidedly enhance the value of the pamphlet.

An important chapter is devoted to "The adjustment of wages by means of sliding scales." The subject is adequately dealt with, but the statement that every scale should provide for full compensation for higher cost of living, whatever the basic rate may be, expresses an ideal which is not always attainable, and ignores the possibility that if the workers in a given industry in a given country refuse to bear any part of the burden of an increase in the cost of living, they may find themselves out of employment as a result of the inability of buyers to pay for the goods manufactured prices which will cover the wages demanded.

## THE USE OF RUBBER IN PAPER MAKING.

RUBBER LATEX, or the sap of the rubber tree, as collected, is a liquid greatly resembling milk, and like milk is really an emulsion of minute insoluble particles. These particles, in the case of the latex, are globules of rubber which after coagulation form the raw rubber of commerce. Coagulation can be prevented by the addition of small amounts of ammonia, and the latex, so preserved, can be kept for a long time and transported to this country without difficulty. It is in this form that it interests the paper maker, for the researches of Mr. F. Kaye, together with experiments on a considerable scale, make it appear that the addition of latex to the stock during the beating operation has a noticeable effect in improving the strength and quality of paper. The object of the beating operation is to bring about hydration of the cellulose fibres, and in some unexplained way the latex appears to assist the process, with a consequent reduction in the time required for beating and in the power consumed. The amount of rubber which actually enters into the constitution of the paper s very small indeed, and is much less than sufficient to impart to the paper any of the characte istics associated with rubber manufactures.

The interest taken in the subject is shown by the large attendance at a meeting of the Rubber Institution last Monday night at the Engineers' Club when Mr. Kaye read a paper entitled "Rubber Latex in Paper Making." Leading exponents both of the rubber-growing industry and the paper-making industry were present and the discussion which ensued was of a practical nature. From the rubber planters point of view the importance of the subject lies in the increased demand for rubber which the process may entail. At present the world's consumption of rubber is far below the producing capacity of the plantations, with the consequence that the industry is in a distressful condition, and unless the demand revives the results are likely to be very serious. The paper produced in the course of a year amounts to about 14,000,000 tons of which half is used for news-prints. It is difficult to say how much of this would ever be made with latex, and it does not seem yet decided how much rubber per pound of paper will give the best results, all things being taken into consideration. From the trend of the discussion one gathered that an average of about 1 per cent of rubber might be used, and that possibly half the paper made might be made with latex. Under such conditions the plantations would have a new market for 70,000 tons of rubber per annum, which is about the present margin of production over the world's demands.

The use of latex in the paper industry would not, of course, find employment for the heavy machinery now used on the plantations to prepare rubber for the market, for the latex would be exported without other preparation than the addition of about 3 gallons of commercial ammonia to each hundred gallons of latex, in order to prevent coagulation on the voyage. The latex contains from 30 per cent. to 35 per cent. of actual rubber, and allowing for freight and for the small extra expense of ammonia, it is estimated that it could be put on the London market at a cost of 1*s.* 6*d.* per pound of rubber content. The latex will mix with water in all proportions, and the only expense the paper-maker would be put to would be in respect of diluting it and pouring it into his beating machines. The addition of 0·5 per cent. of rubber to paper in this way is estimated to cost not more than 18*s.* per ton of paper, the present value of which is about £20. Latex has been experimentally employed by about 30 paper-mills in this country, and the subject is also arousing the interest of paper-makers abroad. It was recently announced in the press that a cargo of 16,600 gallons of latex had been shipped from Singapore consigned to a paper factory in the United States, and that a further order for 3000 tons had been placed. Samples of paper made with various rubber contents were handed round for examination at the meeting and received commendation from paper-makers present. The paper is not waterproofed by the quantity of rubber usually employed, but both the finish and the strength are improved. The paper could also be repulped without trouble.

One speaker raised a very pertinent point in the discussion. If, he asked, the beneficial effect of rubber was not due to its rubbery nature, but to the colloidal properties of the latex, might not further investigation disclose some more easily procurable colloid which would have the same effect. There seemed no answer to this question, as it is not yet demonstrated how the latex accelerates the hydration of the fibre. So far, however, nobody has come forward with a suggested substitute for latex for the purpose. Several possible developments of the process were indicated at the meeting, such as the production of waterproof containers for packing liquid and semi-liquid substances. The dyeing of rubber-treated paper had not been found difficult even when the rubber content amounted to as much as 30 per cent. The best results were obtained with basic colours. Rubber-treated paper had been tested for durability by long continued exposure to sunlight and weather, and it had borne the tests satisfactorily. When a rubber content of 5 per cent. or 10 per cent. or over was used it might be found advantageous to vulcanise it, as the paper was thereby rendered stiffer and stronger.

## EDUCATIONAL SCIENCE.

THE most serious fault attributed to our classical schools was the narrowly specialised course of instruction provided. Unfortunately the reformers who have insisted that any system of education was incomplete from which science was excluded, have themselves fallen into the same error as that they reprobated in others. The result has been that the science courses provided at our secondary schools have tended year by year to be more and more restricted in range. This tendency has been frequently denounced in our columns, and we are glad that a recognition of this trend constitutes the keynote to the interesting presidential address delivered by Sir Richard Gregory to Section L of the British Association. The speaker pointed out that some knowledge of science being an essential to modern culture, it was most important that the courses provided should cover a wide ground, but as a matter of fact in most of our secondary schools general scientific teaching is almost non-existent. Youths still under sixteen years of age specialise in one or two science subjects, and know nothing of other branches. Generally what they do learn is a little of mechanics and of heat, and they leave school without the slightest knowledge of electricity or of astronomy or of the biological sciences. The examination syllabuses have been drawn up on apparently the most short-sighted and unintelligent lines. Even those for the "Cambridge locals" are disfigured by the ridiculous provision, that the candidates' knowledge of his subject is to be such as will be gained from experimental instruction. This leads to an extraordinary waste of time in performing elementary laboratory exercises.

The hours thus lost would be far better spent in firing the youth's imagination by impressing on him what a wonderful world we live in and what science is doing for him every day of the week. It is for example, by no means necessary to the understanding of the work done by those responsible for the purity of our water supplies that the youth should himself experiment on bacterial cultures, nor does the comprehension of the atomic theory necessitate actual experimental work in chemistry or physics. As Sir Richard pointed out, few pupils of their own volition wish to determine specific gravities, or to investigate the laws of motion, or to calculate specific and latent heats. Very few indeed will be engaged in research as their life work, and these will have ample time for specialisation after they have passed their sixteenth birthday.

To insist on laboratory work in the secondary schools is to abandon the claim of science to a position in the school curriculum based on its intrinsic intellectual value. Part of the responsibility for the present misdirection of effort is perhaps to be attributed to Herbert Spencer, who gave the highly pernicious advice that "Children should be led to make their own investigations and to draw their own inferences. They should be told as little as possible and induced to discover as much as possible." Herbert Spencer was himself somewhat imperfectly acquainted with science, and never succeeded in understanding the second law of thermodynamics; but Sir Richard, in quoting the recommendation above cited failed to denounce its futility. At the best very few individuals indeed are capable of becoming discoverers, as is shown by the large number of "researchers" who never succeed in being more than mere "measurers" Those who contribute to scientific thought as compared to scientific data, amount to hardly more than 1 per cent. of those engaged in our laboratories. Even such a striking discovery as that of "radium" did not constitute a contribution to scientific thought, it was merely an addition to scientific data. On the other hand the theory of atomic disintegration which was founded on the much less striking radio-active phenomena associated with thorium, took rank at once as a highly important extension of our views as to the nature of the atom.

Sir Richard again, whilst pointing out that it needed a Priestley and Lavoisier to proceed from the rusting of iron to the composition of air and water failed to emphasize the inherent absurdity of the time-wasting heuristic system as a method of teaching science in secondary schools. He did, however, refer to the claim frequently advanced by some, that knowledge has no scientific reality unless obtained at first hand. If this were true none of us who have not experimented personally with Foucault's pendulum or the gyroscopic compass would have the right to accept the revolution of the earth as an established scientific fact. Moreover, although Maxwell did make many experiments, much of his best work was based on the experiments of others. As Sir Richard pointed out, the wise man learns from the experience of others, and we may recall that it is those incapable of this feat who are stigmatised in the well-known definition of a fool as one incapable of learning by anything but personal experience.

## CONDITIONS IN CONTINENTAL STEEL WORKS.

It is always a matter of interest to know the industrial conditions in competing countries, and at the present time the state of affairs on the Continent is particularly important to both employers and workmen in this country. A report on the conditions in the steel works of Luxemburg and South-west Germany has just been presented to the Iron and Steel Trades Confederation by Mr. Robert Dennison who recently made a visit of inspection to the more important establishments in the area concerned and who has placed a copy of his report at our disposal.

So far as equipment of the works is concerned, Mr. Denison found that the Bessemer basic process is almost universally used, possibly on account of the nature of the local ores which are high in phosphorus and very low in sulphur. The mixers for receiving the hot metal have a capacity of 800 tons to 1,000 tons and the blast furnaces, which are mostly of the latest design, are generally adjacent to the melting shops, thus saving both heat and time. These features, together with the modern method of car-casting, were a large factor in economical production. Rolling mill practice Mr. Dennison does not consider to be superior to our own methods. A noticeable feature of most of the works was the lay-out and equipment of the stock-yards where thousands of tons of sections, from small wire rods to large girders, were available for delivery to customers at very short notice.

As regards wages the report states that it is the custom in the mills, forges, melting shops and blast furnaces to pay the workmen a minimum guaranteed wage plus a bonus on output. The average wage, allowing for the depreciated currency, is low, and though Mr. Dennison saw no evidence of shortage in food or clothing, he remarks that the purchase of butter and milk was beyond the means of the workmen in Southern Germany. The earnings of the men engaged on the more highly skilled operations never exceeded half the wages of men doing similar work in Great Britain, and general discontent was expressed at the small disparity between the earnings of skilled and unskilled men. The lower grades of workmen are said to be better paid than in this country, but no figures are given to support this statement.

Much of the report deals with the social conditions of the workpeople, and the facts stated are interesting. The employers, particularly in Luxemburg "manage the works and the workpeople on the lines of benevolent autocrats." They provide good houses with gardens at a low rent, and in one works a weekly slipper bath is enforced on all employees. At the Dommeldange works all workpeople are medically examined on engagement and lads entering the works are "tested in a psychotechnique laboratory for general physical and mental efficiency." The same works has an institute where "the pupils are made conversant with both the technical and the economic side of their profession, and they are taught to understand the consequences of and the responsibility for their own acts. They also learn to work rapidly without neglecting either the precision or the quality of their work. The institute aims at the formation of character, the development of a liking for work for its own sake on proper pride on the trade adopted." Such a training, assisted by the "benevolent autocracy" of the employers is no doubt largely responsible for the readiness with which machinery for labour saving and increasing production is adopted, a feature which Mr. Dennison rightly considers to be specially worthy of note.

## THE IRON AND STEEL INSTITUTE.

THE York meeting of the Institute was opened last Tuesday at 10 a.m. in the Tempest Anderson Hall of the Museum of the Yorkshire Philosophical Society. In the unavoidable absence of the Lord Mayor of York the members were welcomed on his behalf by Alderman E. Walker, who expressed the gratitude felt by the authorities of the ancient city at this having been selected for the holding of the meetings of the Institute. He, for his part, and the nation as a whole, had not forgotten what metallurgists and scientists had done to bring the war to a successful issue, and he trusted that the deliberations which were going to take place would tend further to improve iron and steel manufacture, to increase output still further, thus enabling this country better to compete in foreign markets. We had the works, the materials and the labour, but what was particularly wanted at the present time was a better feeling between masters and men, both joining hands to forward the cause which was common to all.

Mr. R. L. Wedgwood, C.B., C.M.G., then welcomed the members on behalf of the chairman and directors of the North Eastern Railway Company, and said the Iron and Steel Institute needed no introduction to York. He then referred to the close connection which had always existed between the iron and steel industries, also the coal trade, and the North Eastern Railway, the latter distributing the raw materials and effecting the delivery of the manufactured products. In fact that railway carried more raw materials and products than any other railway in the country, and it was more dependent upon the iron and steel trades than any other British railway. He could therefore welcome the Iron and Steel Institute, as it were, as the senior partner of the North Eastern.

The chairman of the Institute, Mr. Francis Samuelson, thanked on behalf of the members both the above-named speakers. He alluded to the fact that the Institute was formed largely of members directly concerned with manufacture of all classes of iron and steel, but included also scientists whose work consisted in the improvement of methods of manufacture and the better utilisation of the materials produced. York had been selected, as it was central for the visits contemplated, and was the headquarters of the North Eastern Railway Company, who had kindly granted them travelling facilities.

The minutes of the last meeting having been taken as read the chairman gave notice of a resolution in regard to an alteration of by-law 10 (election of President). It is proposed that the by-law shall be altered as follows:—"The president shall be elected for one year," and to omit the words 'and shall not be eligible for re-election until after an interval.'" The reason for this, the chairman added, was that the rule electing the president for two years dated from the first establishment of the Institute, over fifty years ago. At that time the undertakings were very much smaller than they are now and science was in its infancy also. There were at the present time very many more men, both practical and scientific men, who were eligible for election as president. Actual business and responsibility often rendered it a somewhat difficult task to act as president during two successive years. The alteration would give more members a chance of becoming president, and it would also have an effect upon the age of the president. Two years were sometimes too long to wait, and when the occasion occurred the prospective president was older than it was desirable for a president to be. Hence the alteration which did not preclude the possibility of the president being re-elected for a second term. The alteration will come up again at the next spring meeting.

### THE BASES OF MODERN BLAST FURNACE PRACTICE.

The first paper taken was the one having the above title, by Mr. A. K. Reese, who read it in abstract. We reproduce it on page 312 of our present issue.

The discussion was opened by Professor H. Louis, who said that there were many points on which he was in full agreement with the author, but one or two on which he differed from him. One was a point of fact. The author had said that the drying of the blast was first brought out by Gayley in 1904; he was wrong both as regarding date and nationality. Dry blast was first introduced by Charles Cochrane, and a paper was read before the Institute thirty or forty years ago, in which the theory of dry blast was stated, when quicklime was used for drying. An advantage was gained by this dry blast, but the conclusion then arrived at was that the process was not economically a sound one, the dry blast was paid for at too high an expenditure. Some firms had also come to this conclusion in the matter of the Gayley process; at all events the drying of the blast origimated in this country and not in the United States. Professor Louis's second point was a question of opinion. Mr. Reese's object was to arrive at the greatest possible quantity consistent with quality. He (the speaker) doubted whether this was really a sound consideration. The aim should be securing the greatest economy consistent with quality. If one wanted to produce, say, 1,800 tons of pig iron per day, three blast furnaces at 600 tons each could be put down; but it might be preferable to put down six producing 300 tons each, since a greater fuel economy was attainable with a furnace of moderate size. Six were a more expensive plant than three to put down, but the fuel economy would be found to balance charges on capital. Mr. Reese had also said that when the iron ore was too large it was to be reduced in size; if the paper quoted the dimensions of the material giving the best results this would be an advantage.

Mr. Guy Barrett said the author had referred to the necessity of removing all the small coke. He (the speaker) had to work with dirty coal and had found that dirty coke was more prejudicial than its mere size. A way over this difficulty would lie in buying coke upon analysis. Lumpy ore was not altogether an advantage, the ore should be brought down to a more regular smaller size. In regard to the treatment of magnetite ore, he asked whether that could be done using lumpy ore without crushing. The author had found that the flux was of less importance in connection with the question of preparation of materials, whilst he (the speaker) found this of great importance, and the flux should be of regular size, and graded as much as any other of the charge constituents. In the matter of dry blast, Mr. Barrett had an open mind, but had seen instances in America where it had been given up, since, probably, it had not been a very great success financially. He asked whether any difficulty had ever been experienced with the hot blast valves. A furnace having low boshes and a high shaft batter gave the best results; these conditions were fully justified. "Effective bosh area" was a new term, but it had been referred to previously before the Institute. In regard to the large hearth, he agreed with the author's statements and probably the economy it gave had been proved, but a very large hearth was not conducive to the great economy expected from it, it having given rise to trouble out of proportion to the advantage.

Mr. F. Clements was glad to find that blast furnace practice was emerging into a scientific subject, that it was placed under scientific principles and its secrets made open to investigation. He (the speaker) was rather disappointed with the paper, not that he disagreed with the author's cases, the "ten commandments" he had re-stated. The question was as to how far these cases were supported by the author's actual experience. If they were, why had that experience been withheld? Nobody better than the author could give the actual evidence; this, however, was not in the paper. In the matter of breaking the ironstone, he agreed with the author's views, also on the grading of the ore; but this should be viewed from the practical point of view. On considering, say 2,000 tons per day of 28 per cent., iron ore, 1*s.* per ton added to the cost of handling the ore gave 3*s.* per ton added to the cost of the iron, and this immediately introduced a limitation. Had the author any direct evidence to put forward on the value of breaking the ironstone? If it were not broken, what would economically be the difference? The author had also stated eight special advantages resulting from gas cleaning; all the members were familiar with these, but how far in his experience did the technical results compare with the expenditure on gas-cleaning? The right type of gas cleaner was still to be evolved. He asked whether the author had worked a plant without cleaners and with them afterwards, and what had been his results in both instances. He (the speaker) in a former paper of his had stated that the effective bosh area of a blast furnace governed the output of that furnace; the truth of that general law had been worked out both in America and here.

Mr. E. C. Evans stated that the problem of fuel production and utilisation had a great bearing upon the iron and steel industry. He had investigated the structure of coke from the point of view of its combustibility. The author had referred to a coke being subject to a great waste in the upper portion of the furnace before it reached the zone of its usefulness, owing to the greatly increased reaction upon it of the $CO_2$ in the gases. He joined issue with the author on that point. He did not think there was the waste mentioned, and a fuel giving that reaction was one of the greatest advantages a blast furnaceman could get. A fuel of high combustibility was being asked for; it was of a necessity soluble in $CO_2$. Charcoal was more soluble in $CO_2$ than coke, and in this connection he asked how the work done in a charcoal blast furnace could be accounted for. The author had dealt with the preparation of the material, the provision of hot, dry-blast, and so forth; he was trying to concentrate the activity of the furnace as low as possible, and a highly combustible fuel would allow this. A soluble fuel would considerably increase the blast furnace output. To some extent similar considerations applied to the ore; sintered ore was different from ore briquettes in porosity. Coke could be made dense and porous at the same time. The carbon consumption per ton of pig iron in charcoal, from "Bell's principles" was 10·50 cwt.

Mr. E. J. Duff gave his experience with the working of limekilns. Using lump limestone and lump coke, and dumping this material in anyhow gave very irregular results. When the

stone and coke were broken into 4-inch squares regular working was obtained, with but very slight variations.

Mr. D. E. Roberts found the paper to be an historical account, but its author could have added a great deal to it on original work of his own. He (the speaker) was much interested in Mr. Evans' remarks; he knew Mr. Evans' process of making coke, a process which gave much promise. He (Mr. Evans) wanted to make coke something like charcoal. In his (the speaker's) experience, a piece of this coke taken from a burning grate and placed apart had continued burning for quite a long time.

Mr. W. J. Foster referred to former work of his on fuel, adding that in 1902 he had gone into the question and had mentioned the difference between the properties of coke and charcoal. Soft coke was attacked by the gases; the $CO_2$ produced two molecules of CO, with a waste to the coke. He disagreed with the author regarding the density of the coke; the coke was not made dense enough. Dense coke, like the beehive coke was always hard, and what was wanted was to make our dense coke of that character. He (the speaker) also referred to a paper of his read in 1904, in which he gave the calories required for the working of the blast furnace, stating, the number of tons of slag reduced. In the matter of grading, he preferred giving size to the coke and limestone rather than to the iron ore. The iron ore usually melted above the bosh line where was the greatest resistance; it was, therefore, not so important to grade the iron ore. He discussed Mr. Gayley's paper in 1907, and thought that what he described in calories in those days was very near what was found now in practice. He found less coke saving than Gayley did.

Mr. J. H. Harrison called attention to the right distribution of the material in the furnace to be secured when designing a furnace. The author had rightly referred to this, and had said that the falling materials should first strike those in the furnace, when nearly full, at about 18 in. from the walls, adding that the relation of the diameter of the bell to that of the furnace throat, should be a bell diameter 4 ft. to 5 ft. less than the throat diameter. This was true in a sense, but in his (the speaker's) opinion the bell area should be half the area of the throat, the reason being that as the material slid off the bell it dropped more or less vertically, the material then moving outwards. The larger material would roll over, leaving the fines where they first fell from the bell. The gases came up outside and inside an annular column of more or less solid material, and for securing this action a bell area having half the area of the throat was a most satisfactory condition. The author had mentioned as a bell angle 40 deg. to 45 deg. and in some cases 50 deg. This was too steep an angle, with it the larger pieces would have too great a velocity, they would get momentum, roll down heavily and destroy the brick work. Thirty-five degrees was a better angle. The author had also said that the gases had a natural tendency to ascend next to the wall; he (the speaker) doubted that; he agreed that the centre of the charge descended more rapidly than the sides, there being friction against the wall, but could not see why the bulk of the gases should find their way up the sides, against the furnace wall, when they could flow up through a coarser material in the centre. The author had, further, mentioned slips and explosions; it was doubtful whether these were explosions at all. The "top explosion" was the release of compressed gases. At 6 ft. down from the stock line the carbon deposition began and swelled the ore, there being formed a solid plunger in the stack and that finally broke down and dropped. In the matter of temperatures (the author mentioned 1,450 deg. to 1,550 deg. F.), he (the speaker) referred to his own, 1,500 deg. to 1,550 deg., and he was using less coke than other firms working on Cleveland ore. There was an advantage in lowering the bosh; by this means one overcame the difficulty due to the higher temperature of the blast.

Mr. H. K. Scott referred to the Northampton ore, and asked how the author would deal with it, while Mr. C. H. Ridsdale emphasised the necessity of drawing up thorough heat balance sheets.

In the course of his reply, Mr. Reese stated that if Mr. Cochrane was the originator of dry blast, he was pleased to hand over the palm to him, but nevertheless it was Gayley who had brought dry blast to the front. Economy was aimed at when building large furnaces for a large output. In the United States the fuel consumption was lower than here under the older practice. Modern fuel consumption was 16 cwt. per ton for an output of 700 tons; this compared favourably with what was done with slowly-driven furnaces. The furnaces he had referred to were not enormous ones, 90 ft. was the standard size, and the internal volume was smaller than that of the older ones. Large output had a great bearing upon securing economy. In the matter of the size of the ore, it was the usual practice to pass the ore over a 3-in. screen; this depended upon the character of the ore. Dusty material caused difficulty. The magnetite ore was roasted before being crushed. The high blast temperature had an effect upon the non-cooled valves, but the water-cooled ones were not affected. The very large hearth which had been referred to was 20 ft. 3 in. in diameter; that was an excessively large hearth, the proper dimenions being about 16 ft. His paper was not a treatise, but gave outlines of the points on which the furnace practice was based. The facts it stated were based upon his (the speaker's) 35 years' experience, observations and also, to some extent, upon his common sense. Mr. Evans' coke would bring about a radical change in the economical production of pig iron, and his claim was so enormous that it was beyond discussion. He (Mr. Evans) should produce a sufficient quantity of which he might call his "charcoke" to test it properly in a modern blast furnace under modern conditions, and thus to obtain results confirming his statements or otherwise. Mr. Reese confirmed that there was a tendency in the gases to follow up the wall if they can; the smaller material along the wall tended to check the gases at that part and drove them to the centre.

On the members re-assembling in the afternoon of Tuesday, the 5th inst., the first paper taken was on—

AN INVESTIGATION ON THE FACTORS INFLUENCING THE GRAIN AND BOND IN MOULDING SANDS,

by Mr. C. W. H. Holmes, who read it in abstract. We propose to reproduce it in a future issue.

The discussion was opened by Mr. J. E. Fletcher, who stated that in this country too few investigations had been carried out in moulding sands and this was the matter in which foundrymen needed real scientific bases. The Cast Iron Research Association had been giving attention to the question for some time past. He hoped the author's work was only the commencement of his investigations. There was a great need to examine the mechanical characteristics of moulding sands, quite apart from their chemical constituents. There was a great difference between the old-fashioned tests which consisted in shaking sand in water and waiting for the deposit to be formed, and research work stating the colloidal effect of the clay part of the sands. The results quoted in the paper would be found of importance and the members looked to the author for more information on the varieties of sands in the country. The Cast Iron Research Association was at the present time engaged on getting out a catalogue of these. More information was also wanted in regard to liquid metal erosion, also on bond adsorption values. The use of dye was a qualitative test, but did not seem yet to be quite satisfactory. He asked the author whether he had tried a circular transverse test as against a square one? He (the speaker) did not see in the paper any reference to the cantilever test of sands; this might have been useful for comparison with his (the author's) other tests.

Dr. Hatfield congratulated the author upon his conclusions, with which he was in full agreement, and endorsed the previous speaker's remarks. Moulding sands were difficult to test. He (the speaker) confined his investigations to ascertaining the mechanical and physical properties, and it would be greatly interesting to iron and steel makers to have a simple, ready and effective method for determining the suitability of a sand. The actual casting operation had been hitherto the only satisfactory test for arriving at the value of a sand. He had seen in France, in the Pas-de-Calais, a foundry working with sand dug up from a neighbouring field; it was used as green sand and gave perfect castings. What was wanted was, he repeated, a method showing why such and such a sand was a good one, or otherwise.

Mr. E. Adamson and Mr. T. Lester expressed their satisfaction at the author's contribution, the latter stating that the problem should be dealt with until standardisation be arrived at. Mr. H. K. Scott's remarks were to the same effect and he laid stress upon the fact that other material, such as dung, was mixed with the sand, this having an effect to be reckoned upon.

In the course of a brief reply, Mr. Holmes said the cantilever test was not smooth enough for weak moulding sand; there was a slight jerk which was fatal. He hoped to continue the work and to be able to propose tests other than the actual casting test, but was afraid this would take a long time. In the matter of additions, he added that all his sands were green sands. In reply to a question asked by Dr. Hatfield as to the bright metallic surface of a casting arrived at by adding coal dust to the sand, Mr. Holmes stated that he thought a cushion of gas was formed and this deposited carbon on the surface; it was probably a physical effect only.

ON THE DIMINUTION OF LAG AT Ar1 THROUGH DEFORMATION.

The next paper was the one having the above title by Mr. J. H. Whiteley. We propose reproducing this in a later issue. It was read in abstract by the author.

Dr. Hatfield found the lag to be in conformity with analogous cases in chemistry, and it was reasonable to argue that hammering, for instance, gave the effect referred to. The author's experiments were interesting and he congratulated him upon them. He agreed with the author's summary to the effect that there was evidence to show that when steel, in the metastable region at the Ar 1 point, was worked, lag was markedly diminished.

THE NITROGENISATION OF IRON AND STEEL BY SODIUM NITRATE.

The last paper taken on Monday was the one by Mr. L. E. Benson, the title of which is here given. Mr. Benson read it in abstract. We propose to reproduce it in a later issue.

Mr. J. H. Whiteley called attention to a paper read before the Faraday Society by Mr. Jones, of Woolwich Arsenal, on stressed steels; in which he dealt with the solutions of nitrates. He (the speaker) thought the author had no evidence that his crystals were really nitrides and suggested they were nitrates.

Mr. Saniter said it was a very easy matter to ascertain whether they were nitrides or nitrates; the water on the polishing pad would dissolve nitrates. Dr. Hatfield asked how the author could give an equation to account for the nitrides of iron.

In the course of a brief reply, Mr. Benson said he had used water on his polishing pad, and, as Mr. Saniter had stated, nitrates were soluble in water. The "nitride structure" was in his specimens.

On Tuesday afternoon after the meeting, Mr. W. McConway gave a film demonstration descriptive of his new process for the production of steel discs by centrifugal methods direct from molten steel.

## THE BRITISH ASSOCIATION AT HULL.

THE ninetieth annual meeting of the British Association for the Advancement of Science opened at Hull on Wednesday. It was announced that 1558 members were present, and that more were expected on succeeding days.

The "Handbook of Hull and the East Riding of Yorkshire," which has been prepared by a Committee for the visit of the British Association and has been edited by Mr. T. Sheppard, M.Sc., F.G.S., is once more a very instructive volume (of 532 pages), dealing with the history and the public institutions of Hull and the fauna and flora of the district. There is no special chapter on the docks; but that especially important subject will receive adequate consideration in various sections during the meeting. The chapter on the "Rise and Progress of Hull" is due to the late Sir Albert Kaye Rollit, a Hull man

prominently connected with the municipal and industrial development, shipping and politics of Hull. He was a Past President of the Chambers of Commerce of Hull and of London, and his death on August 12 is a great loss to the Association.

The President-Elect, Sir Charles Scott Sherrington, Pres. R.S., M.D., of Oxford, delivered his address in the City Hall at 8.30 on Wednesday evening. In introducing the President elect, Sir Edward Thorpe, the past year's president, first referred to the great losses the Association had quite recently sustained by the death of Dr. W. H. Rivers and Sir A. K. Rollit. He then turned to the generous donation by Sir Charles Parsons of 10,000*l*. Sir J. Caird had given the same sum at Dundee in 1911. Finally, Sir Edward spoke of the protest he had made against the use of poison gases last year at Edinburgh.

### Some Aspects of Animal Mechanism.

As a physiologist and biologist, Sir C. S. Sherrington has had several distinguished predecessors in the presidential chair of the Association, Lister, Michael Foster, William Turner, Ray Lankester, Edward Schäfer and W. Bateson. They had all, in their addresses, discussed the profound problems of life, evolution and heredity, which are ever before us and which no apparent advance seems to make less remote. Without any retrospective survey, Professor Sherrington in his address on "Some Aspects of Animal Mechanism" at once put the questions: "Is the living organism a machine? Is life the running of a mechanism?" He dealt with the "how," the working of the organism, and especially with the nervous mechanism—his own particular field of work—while purposely refraining from speculating on the "why" of the living organism. Much of what he said is the result of quite recent researches, upon which his predecessors could not have dwelt.

Not a few of the processes of the living body, Sir Charles remarked, muscular contraction, the circulation of the blood, the respiratory action, the nervous impulse and its journeyings, are sufficiently known to let us hope that further application of physics and chemistry will furnish a competent key. We claim to comprehend the working of a gas engine, though we cannot construct the atoms of the gas engine. The blood composition is kept relatively constant, and the breathing is controlled by nervous centres which make the slightest increase in the partial pressure of the carbon dioxide at the bottom of the lungs at once increase the ventilation of the chest. The erect posture of the body is maintained by the intervention of two tiny water-filled gravity-bags, one on each side of the skull. Attached to the hairlets of each of these bags is a tiny crystalline stone which, when shifted by the inclination of the head, slips microscopically and presses more on a special nerve, causing movement to the right or to the left. The same stones keep the eye balls erect. The nervous system consists of chains of cells and fibres; only strong impulses seem to be able to pass across their link-junctions, where the traffic is regulated as in a railway system. The cut nerve tries to reach the muscle again, which is paralysed without it, and generally does reach it, guided in some way; yet the growth is blind, and nerve-growth is peculiar like all cell growth; without tissue the nerve loses its special character.

"Made up of myriads of cell-lives, individually born, feeding and breathing individually within the body, each of us nevertheless appears to himself a single entity." Some factors, those of sex determination and heredity, seem to affect the character of every dividing cell of the whole body. But mind, mentality, seems to attach itself to life only when there is a nervous system, and mentality seems to be concentrated in the cortex of the fore brain, a comparatively modern structure superposed upon the ancient non-mental brain. Mental action and nervous machinery are both subject to fatigue, they both leave a memory behind, and have momentum and inertia. "But the nexus of the mind, with its bodily place still seems utterly enigma." Even if we understood the whole production of the body from the egg to the adult, we might have merely a "reflex pet" devoid of mind. The engineer would find it difficult to make a motive machine out of white of egg, some salts and thin membrane. Yet that is what Nature has done in muscle. "Can we understand a unified entity which is part mechanism, and part not?"

The vote of thanks to the President was proposed by the Lord Mayor, who extended a hearty welcome to the Association, and mentioned that Sir James Reckitt had been present at the Hull meeting, 1853, though he was not well enough to be present now. The vote was seconded by Sir Edward Schafer, who was President of the Psychologist Section at Dundee, 1911.

The various sections met for the consideration of papers, &c., yesterday (Thursday), including Section G, at which meeting there was a discussion on "The Strength of Railway Bridges." This discussion was introduced by a few remarks by Mr. J. S. Wilson, after which three papers were read. The first of these was entitled "The Strength of Railway Bridges, with Special Reference to the Proposals of the Ministry of Transport." This was by Messrs. R. G. Cookson and J. S. Nicholas. The second, by Mr. Conrad Gribble, was entitled "Present-Day Problems and Tendencies in Railway Bridge Design," and the third, by Mr. J. S. Wilson and Professor B. P. Haigh, was on "The Influence of Rivet Holes on the Strength and Endurance of Steel Structures." These papers are reprinted elsewhere in this issue. The discussion on them will be given in the general report of the proceedings of Section G, which we shall commence to publish in our next issue. The meetings of the sections are continued to-day, and the programme will not end until Wednesday next.

## INDUSTRIAL NOTES.

The fifty-fourth annual Trades Union Congress was opened at Southport on Monday.

Mr. R. B. Walker, the new president, read an address in which he reiterated the charge that the employers had seized the existing economic situation as an excuse for reducing wages, the inevitable inference being that full employment could have been found for the workers at the old rates. This claim, indeed, was very definitely made by Mr. John Hill in the August report of the United Society of Boilermakers and Iron and Steel Shipbuilders, and apparently labour leaders believe that the public will accept the statement if repeated sufficiently often. Unfortunately a considerable section of the public are convinced by continued reiteration, but the remainder, who are the people whose support is really important, demand some evidence in the support of the contention that the reductions in question are due to pure wantonness and ill-will on the part of the employers. The unions were offered the chance of acquiring the Chepstow shipyard on extraordinarily favourable terms, but apparently in spite of the boom then at its height, they did not imagine that orders could be obtained so easily as they now assert. It is, of course, quite true that high weekly takings by the operatives are by no means incompatible with low costs of production. The cheapest motor car in the world is produced by the highest paid rank and file, but to secure this result it has been essential that the employer had full managerial control, a condition to which Mr. Walker most strongly objects. Foundrymen have been heavily fined by their union for working 10 minutes overtime in order to save an important casting. Such interferences with works management are incompatible with low production costs, and these, as the wiser labour leaders recognise, are essential to the maintenance of our export trade.

The address contained some of the conventional attacks on capitalism. The speaker has apparently been able to persuade himself of the absurdity that bad trade and depression are good for the capitalist, whom he accuses of "pushing the *advantage* they derive from the situation to the uttermost." Of course there is the stock remark that capitalism has failed, but the apologists for the present system of industrial organisation may justly claim that it is associated with a higher average of comfort and decency amongst the "common people" than has ever previously been attained in the whole history of the world. This was to some extent pointed out in a courageous speech by the Lady Mayoress of Southport. Indeed as was shown by Mr. Asquith's daughter when supporting her father's Parliamentary candidature, women seem much more ready than men, to state frankly and publicly what they really think on labour matters. Economists have called in vain for any evidence that matters would be other than worsened by the control of industry by the recognised "labour leaders" whose schemes for reconstituting society have invariably failed, wherever adopted, even by communities whole-heartedly convinced of their value. Some of the wiser leaders are now beginning to recognise this, and although it is perhaps too much to expect a complete withdrawal and retraction, they are now advocating the policy of making the best of things as they are, and this advice, if generally adopted, will undoubtedly result in a substantial improvement of the general well-being.

Most of us find very great difficulty in deciding what exactly is the moral and material situation in Germany. The available evidence is most conflicting, but no such doubts assail the Trades Union Congress. Relying largely on the testimony of the men and journals that so grievously deceived us about Germany before the war, the Congress is as confident now as its advisers were in 1914, that Junkerism and militarism are negligible factors in the framing of German policy. This may, of course, chance to be right, but the refusal to permit of the punishment of war criminals, and the statements of the members of the American legion now visiting this country, which receive support from an article in last month's *Fortnightly* indicate an entirely different condition of affairs. In short, the evidence available is extremely contradictory, and so far as conditions are bad, they appear to be due rather to the unrestrained issue of paper money, than to the demand for just reparation.

In another section of his address, Mr. Walker appears to assume that in all industrial conflicts, the union is in every case in the right, and the employer wholly in the wrong. Men being men, it is impossible that this should be the case, and it is undoubtedly true that large sections of labour deemed many of the miners' claims unreasonable and inequitable. Mr. Walker, however, demands that even in such cases the belligerent union should be supported. This appears to be a new reading of the old maxim "my country right or wrong," where in accordance with the internationalist views held strongly by some labour leaders, feebly by others, and hardly at all by the rank and file, the word country is replaced by "labour."

There is one curious contrast between statements on the industrial situation by labour and by the representatives of employers. The former deal almost exclusively with generalities whilst the others state definite facts, as for instance that during the war when skilled men were replaced on piece work by girls, the latter in certain cases made about double the men's weekly takings. The case of the foundrymen who were heavily fined for working 10 minutes overtime has already been mentioned above, but comment on such specific instances of reprehensible practices is studiously avoided by labour leaders. Indeed, they very seldom make mention of specific instances of equally dishonest or discreditable practices on the part of the employer which unfortunately are not wanting. Should they attack these, giving specific dates, they could count on the whole-hearted support of the general public. It is a curious fact, that we cannot recall a strike over such cases of sharp practice; though a good deal of grumbling may occur in the shops.

At the meeting of the Trades Union Congress on Thursday, Mr. Herbert Smith, referring to the pit disaster at Whitehaven, suggested that there would be fewer such accidents had the men themselves greater control over the management. This appears inherently improbable in view of the immense amount of study which has been expended on the reduction of mining risks, but the introduction of safety committees composed mainly of workmen's representatives could do no harm, and would render impossible the suggestion implied rather than stated that men's lives are being sacrificed by the callousness of the management. In the less dangerous trades, such safety committees have done much useful work, but it may be doubted whether their establishment in explosive works would materially improve matters, and probably the same would be the case with mines. The moral effect of their introduction might, however, be by no means of negligible importance.

Very important questions are raised by the action of President Harding in obtaining an injunction restraining strikers from interfering with the operation of the railroads. Similar action was taken many years ago during President Cleveland's administration, but there has been a growing tendency of late years to claim that organised labour is above the law, a claim which was to a certain extent recognised in this country by the Trades Dispute Acts, which relieved the unions of responsibility for any wrongful acts done by their officials in the course of a trades dispute. In America this feeling would also seem to have grown as Mr. Samuel Gompers, the president of the American Federation, has expressed great indignation at the Government's action. It is highly important, however, that this

claim should not be recognised. In the past history of the world small organised minorities have secured complete control of whole communities, very often no doubt to the general advantage; but the whole drift for many centuries has been in the direction of democracy, and it would be a poor sequel to the abolition of absolute monarchy, to be subjected to the domination of another organised minority arbitrarily denying the right of the individual to proceed on "his lawful occasions." The railway men have quite properly a legal right to strike, but this does not include any moral right to abandon trains in the midst of a wilderness, nor to interfere with the running of the trains by other sections of the community.

Some interesting data as to wage rates per hour in different parts of the United States are given in a recent issue of the *Engineering News Record* from which we abstract the following :—

| Occupation. | Baltimore. | Boston | Chicago. | New York. | San Francisco. |
|---|---|---|---|---|---|
| | dols. | dols. | dols. | dols. | dols. |
| Bricklayer .. .. .. | 1·25 | 0·90 | 1·10 | 1·25 | 1·12½ |
| Carpenter .. .. .. | 0·80 | 0·90 | 1·00 | 1·12½ | 1·00 |
| Hoisting Engineers .. | 0·87 | 0·90 | 1·10 | 1·25 | 1·00 |
| Hod Carriers .. .. | 0·54 | 0·60 | — | 0·87½ | 0·75 |
| Pile Drivers .. .. | 0·74 | 0·90 | 1·10 | 1·00 | 1·00 |
| Structural Ironworkers .. | 1·00 | 0·90 | 1·05 | 1·12½ | 1·12½ |
| Common Labourer .. | 0·30 | 0·55 | 0·72½ | 0·50 to 0·60 | 0·47½ to 0·50 |

It has long been a recognised principle that as far as practicable, wages in the different trades and industries should be such that equal knowledge, skill, responsibility and industry should reap approximately equivalent rewards. This principle appeared to be challenged by Mr. Ernest Bevin in an address delivered to the Lancashire tramwaymen on Sunday afternoon last. As is well known, our national existence is very largely dependent on our exports, and to maintain these it has been necessary to reduce wages in many trades, and there being no obvious reason why trades not subject to foreign competition should be accorded a privileged position, there has quite properly been a demand that tramwaymen's wages should suffer a corresponding reduction, otherwise they would of necessity be supported by high fares drawn from the pockets of those worse off than themselves. This adjustment was strongly condemned by Mr. Ernest Bevin who, oblivious of the record of the iron and steel industries, declared that sliding scales were only adhered to by employers when they resulted in continued reductions of wages.

At Tuesday's meeting of the Trades Union Congress, Mr. John Hill said that during the recent "lock-out" in the engineering trades (which was occasioned by the interference of the shop stewards with the management), the proposal that all utility services, light, trams, and water in London should be held up, had been very carefully considered and set aside as an impracticable way of solving the difficulty. It is interesting to note that experience is at last bearing its fruit. Apart from revolutionary violence, it is not such an easy matter to hold up public services in London as was proved during the railway strike, when volunteers soon got Lots-road into operation, and had they been longer in charge would, it is asserted, have been working it more efficiently than the regular crew. Again, during the coal strike, the attempt was made to hold up the tramway power station at Greenwich and resulted in an ignominious failure. The controlling factor of the situation is that more than sufficient knowledge and ability exists outside of the unions to run all essential public services, provided the volunteers are protected from personal violence. This was very clearly demonstrated during the perfidious municipal strike at Leeds in 1912 when, in defiance of their pledged word, the tramwaymen struck in concert with the other employés of the city. Mr. Bevin also asserted that industrial courts could not be relied on to give the workmen fair treatment. Mr. J. H. Thomas, on the other hand, has declared that the Industrial Court had justified its claim to the worker's confidence.

The Silver-hill Colliery, in the Nottinghamshire coalfield, which was closed down a week ago on the ground that it was not paying, is to be re-opened, the miners, to the number of 600 or 700, having accepted the terms offered by the owners, which involved a wages concession on the part of the men. The concession is stated to be 2*d.* off the basic rate per ton.

The ballot of the members of the Typographical Association shows a majority of over two to one in favour of acceptance of the recommendations of the executive for a settlement of the recent dispute, and the wage reduction terms which were negotiated in London.

The Ministry of Labour states that on August 28 the number of persons recorded on the live registers of the Employment Exchanges in Great Britain as wholly unemployed was 1,331,400—2,289 fewer than in the preceding week, and 492,333 fewer than at the beginning of last January. The number working short time and drawing benefit for intervals of unemployment on August 28 was 63,400, compared with 65,105 on August 21 and 934,786 on July 1, 1921.

## "DOUBLE REDUCTION GEARS FOR TURBINES."

TO THE EDITOR OF ENGINEERING.

SIR,—I have read your recent leading article on Double Reduction Gearing and Mr. W. C. Rowden's letter to you on the same subject with considerable interest. It now appears certain that some immediate relief, if not a complete solution, can be obtained by the use of suitable steels. Under these circumstances it appears premature to consider re-design of the gears or other and less efficient methods of speed reduction, until steel makers and forgemasters have provided a forging which is the most likely to comply with the demands made on it.

Material of high elastic limit is required so that heavy loads can be carried without permanent deformation; further, to deal with abnormal but very local loads, which give rise to stresses exceeding the elastic limit stress, a high izod impact figure is essential, as this test indicates the ability of material to deal successfully with these conditions. The heavily stressed places will not easily open up into cracks, and finally fail, if the Izod figure is high.

The foregoing requirements limit the choice of material to alloy steels with a nickel-chrome basis; these are the steels recommended. Nickel chrome alone might be suitable under some circumstances, but the addition of the rarer alloying elements undoubtedly gives a safer material. Thus, for example, Messrs. Armstrong, Whitworth's "Vibrac" steel has the important additional advantage of showing no "temper brittleness" under any conditions of treatment. It would be very interesting to know if the failure of a "tough" nickel chrome pinion has yet occurred.

Your obedient Servant,

Greenock, September 4, 1922. WESLEY AUSTIN.

## "EVAPORATION AND DISTILLATION."

TO THE EDITOR OF ENGINEERING.

SIR,—Being much interested in the subject of evaporation, and having in my time made many tests upon a great variety of evaporating apparatus, I was much struck by the remarkable figures given in the letter from Mr. Jas. B. Maclean which appeared on page 176 of your issue of the 11th ult. As Mr. Maclean's letter arose out of an address delivered by Professor Hinchley in Glasgow, I have been looking for some reply from Professor Hinchley. Perhaps it will still appear; in any event I would like to ask Mr. Maclean if he would, in the interest of practical science, explain in your columns the means by which the extraordinary result set out in his letter was attained. According to the formerly accepted laws of physics, such a result is impossible, but in these days, when one may speak disrespectfully not only of the equator but even of the law of gravity itself, one hesitates to describe anything, reported by a competent observer, as impossible.

I feel sure that you would willingly give Mr. Maclean the necessary space to explain the amazing achievement of his apparatus.

I am, Sir, yours very truly,

A. J. LIVERSEDGE.

National Liberal Club, London, September 1, 1922.

## "THE COMMERCIAL VALUE OF KNOWLEDGE."

TO THE EDITOR OF ENGINEERING.

SIR,—One's natural sympathy with the men who were fighting for the country during the years when, under normal circumstances, they should have been getting their engineering training, makes it difficult to criticise such letters as that of "Graduate" in your issue of September 1. Ex-service men are in a class by themselves and deserve separate and special consideration. Your article, as I read it, deals with the outlook for the average University graduate, and points out how little value employers attach to the kind of knowledge which an engineering degree certifies. The letter of "Graduate" really confirms your views, for it would never have been written had an engineering degree been an easy passport to employment. Incidentally, also, it shows the curious misconception of what engineering really consists of, which is at the root of so many disappointments when practical life has to be faced. Your correspondent states that "the degree and diploma requirements are such as to eliminate all but the practical man." Now it is a fact—and the university course described in his letter bears it out—that a degree in engineering can be obtained by a man who has never even set eyes on an engineering works in his life. To call such a man a practical man is regarded by employers as absurd. He is as far from it as a youth who has studied books about the North Pole is from being a practical Arctic explorer.

Your remark about the impossibility of learning engineering backwards is very important. To try and teach a young man the theory of the action of things before he really has any proper acquaintance with the things themselves is to try to put the cart before the horse. This, however, is what is attempted by those who direct engineering education, with the result that a false view of the relative importance of things is often acquired. The employer, unfortunately, does not express his ideas so publicly as the professional teacher, but he shows his disapproval of present methods by his valuation of the product.

Would it not be possible for a representative committee of actual works managers to be formed, quite free from the influence of the professional element, in order to issue a specification of the type of youth they want in their works. This would state maximum and minimum age limits, and the nature and extent of the education desirable in special subjects. Parents would then have the views of real engineers as to the most favourable conditions of entrance to engineering, and by acting in accordance with them, would find much less difficulty in obtaining a start for their sons. The industry on the other hand would benefit by a supply of recruits of the kind it really needs. I think most works managers would agree that the best engineers are turned out by subjecting boys to the atmosphere and discipline of the works as soon as they leave school, making them get their technical education concurrently with their workshop experience, and putting on the finishing touches at a college afterwards.

Yours faithfully,

September 4, 1922. "SPERO MELIORA."

TO THE EDITOR OF ENGINEERING.

SIR,—"Graduate" seems to be greatly disappointed because he cannot obtain an appointment "after weeks of patience to secure a post in the humblest capacities." There are mechanics to-day who have "academic distinction" combined with years of practical and proved capabilities, who would only be glad to accept a situation on the lowest rung, who have been advertising for months in more than one engineering journal, in the vain endeavour to secure a berth.

The employer of to-day is not a philanthropist. None of them can pay 3*l.* per week to a junior draughtsman for the sake of giving him employment when he has young men in his works with three and four years workshop and science and art evening class training, who are clamouring to be admitted to the drawing office with their wages about half the "minimum." I do not use these words to dishearten "Graduate." He is a young man setting out in life, and I wish him every success. Most likely he will say to himself, "Fate has decreed it and fate is the very Devil." But if the intended purchaser won't pay the price the manufacturer must have, in view of the cost of production, unemployment must remain.

In reference to the Government offer of higher education for ex-service men, it was a case of the Government doing their duty, to compensate those who were debarred from learning a profession or trade, owing to being called upon for active service. But it is common knowledge that applications were made for admission to colleges, &c., by many who, previous to joining or being called up, had been employed as skilled mechanics, and who, but for the special conditions prevailing, would never have entered college. Young men, too, with several years training as French polishers, applied, and were admitted to be trained as dentists, whether they were adapted for such profession or not.

No doubt it was a "nerve-shattering war," but there were no such privileges offered to the young and middle-aged men who were forced to work night and day to produce shells; if they attempted to make a practice of having a day or night off, to recuperate their health, they generally were presented with their "papers" to join up. Those who were not called up "stamped their card and paid their income-tax" : when the armistice was signed, they were "demobilised" and received the dole, but no golden opportunity was offered to them to enter a "swanky profession." These young men to-day are now comrades in arms along with "Graduate."

Yours truly,

ROBERT KEDDIE.

12, Venus-road, Eltham, S.E. 9, September 4, 1922.

TO THE EDITOR OF ENGINEERING.

SIR,—Could there possibly be better evidence than the latter part of "Graduate's" letter to prove the soundness of your judgment on this question?

*Who* advised these poor young fellows to become ex-Service students in order to swell the ranks of "paper-collar" engineers for whom employers have no need and for whom working mechanics have no respect?

The college-trained youth is at a discount, and there is a reaction against the man who *knows* so much that he hasn't time to *do* anything! If "Graduate" had gone for three months to a blacksmith and three months to a village carpenter or wheelwright, he might then have got a job at a small engineer's works to learn turning and fitting for a year, during which he could have had lessons at night from a draughtsman, and, after this, a year at a "college" would have enabled him to absorb "knowledge" which his practical experience had taught him the need of. He would then have stood some chance of employment.

Yours truly,

London, September 2. ANTI-PROFESSOR.

PROPOSED TUBE RAILWAYS IN INDIA.—The Office of the High Commissioner for India has forwarded to the Department of Overseas Trade copies of Reports on the proposed tube railways between the East Indian Railway and the Eastern Bengal Railway, together with a book of plans and a longitudinal section. These documents can be inspected by representatives of United Kingdom firms interested on application to Room 49 of the Department of Overseas Trade, 35, Old Queen Street, Westminster, S.W. 1.

## PRESENT-DAY PROBLEMS AND TENDENCIES IN RAILWAY BRIDGE DESIGN.*

By CONRAD GRIBBLE, Assoc.M.Inst.C.E.

UNDOUBTEDLY the guiding motives to-day, in bridge design, are a desire for economy both in first cost and in subsequent maintenance, and a striving after a more accurately-designed structure in which there are no weak links. The necessity for stronger bridges which will safely carry modern locomotives and the experience gained in a century of fighting against corrosion of metallic structures, have compelled engineers to consider very carefully what are the best materials to employ in order to provide not only the strongest, but also the most durable, form of bridge.

The problems confronting railway engineers in the Old and New World respectively, are rather different, since in this country, for instance, we are not so greatly concerned with the design of long span bridges carrying new railways over wide rivers and estuaries, nor as yet with the replacement of such long spans as we possess. The greater part of the railway bridge engineer's time is spent in the calculation of the factor of safety of existing structures of moderate span, and the renewal of such as are ascertained to be deficient in strength. The time has come when a great number of wrought-iron bridges constructed during the latter half of the nineteenth century are becoming obsolete either on account of their original strength being inadequate to face modern conditions or because corrosion has taken too heavy a toll of their strength.

Thirty years ago the use of wrought iron began to cease on the introduction of mild steel, and the newer material has not been superseded to any appreciable extent, despite the invention of high-tension alloys, and the fact that for the smaller bridges at any rate, concrete is being employed to an increasing degree either as an encasement for steel girders or in the form of reinforced concrete.

In his last work, "Bridge Economics," Dr. Waddell is optimistic about the future of alloy steel for long-span bridges where its greatly increased strength will no doubt render it economical. Since the main problem with very long girders is to design one which will carry itself, and the moving load is comparatively small, the material which possesses the greatest strength relatively to its weight is likely to prove economical, even if its cost is considerably greater per unit of weight than that of the cheaper and weaker material.

The use of expensive alloys, such as nickel, chrome or manganese steels for ordinary bridges is not at present justified, since the lightness of the structure is not the governing factor, and in fact, many engineers appear to aim, at present, at durability rather than lightness.

The most recent invention of the metallurgists, known as stainless steel, is more attractive to the majority of bridge engineers; and although its introduction in the form of girders would not be welcomed by the numerous purveyors of paints and asphalts who vie with each other in urging the claims of their particular products as protective coatings for steelwork, yet it would be the most valuable improvement from the point of view of railway engineers which one can at present visualise, provided that its strength is at least equal to that of mild steel, and that it has the necessary toughness and malleability.

Until, however, a non-corrodible material is available, engineers must devote their studies and energies towards protecting bridges from corrosion by ensuring that all steelwork is isolated from moisture by concrete, asphalt or paint, and that such protective coating is permanent or easily renewable. The floor system is the most vulnerable and most difficult of inspection, and certain engineers insist on concrete floors wherever practicable, without considering first cost or weight. In the case of renewals of bridges under traffic, concrete, except in the form of pre-cast units, is hardly feasible, and considerable ingenuity must be employed in its adoption under these conditions.

Every maintaining engineer realises the ravages which have taken place in iron and steel bridges through oxidisation, especially in districts where the atmosphere is laden with chemicals, and a great deal of the expense now being incurred in the renewal of bridges might have been saved if corrosion had been more successfully fought.

Concrete cannot easily be applied to large structures owing to its great weight, but there are great hopes that the cement gun will prove a useful appliance for providing a thin and impermeable coating to girder work.

It is claimed that concrete so formed is of such a dense nature that a thin coat is effective. It is being used in the United States of America on a very large steel arch at present being built in a district notoriously detrimental to steelwork, where the weight of a poured encasement would have been out of the question.

The renewal of railway bridges is so expensive on account not only of the cost of steelwork, but also of the difficulty of maintaining traffic during the progress of reconstruction, that the engineer's first aim in the design of a bridge should be to ensure as long a life as possible.

In the case of a structure such as the Forth Bridge, one can only conceive of its being replaced piecemeal when the time comes for it to be renewed, and that day is still, we hope, far distant. The care which is taken in the case of this bridge by means of constant inspection and painting, will be well repaid, and equal care in the design and maintenance of steel structures generally is absolutely essential. It is pretty generally recognised by engineers that although steel is a stronger material than either cast or wrought iron, it is very much more corrodible than cast-iron, and rather more so than wrought iron, and all economy in weight due to its additional strength is very quickly sacrificed if its life is shortened by increased corrosion.

*Problem of Secondary Stresses.*—Accurate designing of bridges is of course an absolute impossibility if we understand by the term "accuracy" a precise proportioning of each part to the maximum stress which it will have to bear. If it were possible to ascertain exactly the stresses in each member of a bridge, nearly half the metal employed could probably be saved without diminishing the true factor of safety possessed by its weakest part.

It is certain, however, that the stresses are, and always will be, indeterminate, and that all that can be done is to endeavour to make the structure of as uniform strength as possible by the adoption of reasonable assumptions.

The principal faults that one finds with the design of girder bridges in the past are due to a failure to appreciate the assistance which one part gives to another and to allow for what are generally described as secondary stresses.

Modern practice inclines strongly towards making such allowance, but engineers are by no means agreed as to the amount of extra metal which must be added in particular cases, nor as to the extent to which the secondary stresses in certain members relieve the direct stresses in others.

Recent experiments in Switzerland have shown clearly how the floor system of a lattice girder bridge assists the main girders by taking part of the tension stresses generally assumed to be borne entirely by the flanges.

Numerous tests have been made to demonstrate that cross-girders should be considered as partially *encastrés* beams, and that stringers, although in short lengths, framed between the cross-girders, are by no means freely supported beams. A continuous deck-plate attached to main girders and floor members is really an additional flange, not only to the floor members, but also to the main girders.

The author rather regrets the term "secondary stresses," as there seems to be a widespread idea that such stresses are of secondary importance, whereas it is obvious that all stresses must be of equal importance if they occur simultaneously, and the only stresses which may be ignored are those which do not occur at the same time as those which produce maximum stress, and thus do not contribute to nor relieve the maximum stress.

*Research Work on Bridges.*—The only way by which it is probable that accurate methods of design can be attained is by experiments on existing girders, and these should not be directed merely at ascertaining the actual stresses which occur during the passage of locomotives over the bridge, but should also be employed to discover the manner in which, and the point at which, the bridge fails. The difficulty of conducting breaking or crippling tests of large bridges is considerable, but the author would like to suggest that as numerous bridges are removed by various railway companies every year, some of these might, with considerable advantage, be reassembled and loaded to breaking point, if a suitable plant could be obtained.

The applied load would be merely static and not moving, but this method of testing would be perfectly satisfactory since separate tests of bridges *in situ* can be carried out to ascertain the ratio between maximum stresses under static and speed conditions.

The plant required is simple: Merely a plot of land with siding access and either a travelling overhead crane or a couple of locomotive cranes which would erect the bridge and apply the load. Deflections and stresses in various parts would be measured by suitable instruments.

Railway engineers would perhaps have more confidence in the results of a few tests to destruction on full-size bridges than in many stress records as usually obtained.

*Rivets.*—Judging by the sound condition of many old girder bridges, the rivets in which fall very short of modern standards, both in number and size, we must be putting far too many into new bridges to-day, and yet most engineers consider that money invested in rivets is well spent since the strength of a structure is the strength of its connections.

It is nevertheless true that girders are being removed from the line now-a-days on account of deficient flange area, which have an enormously greater deficiency of strength in the rivet area provided between the web and the flanges. It is not at all remarkable that the girders have not failed in tension seeing that the stresses, although higher than are considered proper, do not, as a rule, approach the elastic limit of the material. On the other hand, the stresses in the rivets are, according to our usual methods of calculation, far beyond the elastic limit, and yet these show no signs of failure.

Since we continue to provide rivets in new work on the same basis as that by which we calculate these impossible stresses in old work, it necessarily follows that we are providing considerably more rivet area than is really required. The author would much like to see experiments on riveted plate girders in some of which the riveting has been deliberately arranged to be the weakest part, and the actual loads necessary to cause rivet failure can be measured. In such a series of experiments, the precise proportion of rivet area which would ensure direct failure of flange or buckling of web could be easily ascertained, and the results would be of the greatest value to bridge engineers. Riveting is expensive, and the drilling of holes inevitably reduces the available flange area of a girder, and if it can be reduced, distinct economy will result. Although riveting between various component parts of a structure can hardly be overdone, *e.g.*, between cross-girders and main girders or between decking, stringers and cross-girders, yet it is quite possible that the riveting designed to transmit stress from web to angles and from angles to flanges in plate girders, is much in excess of the necessities of the case, either on account of errors in our formulæ for calculating the stress in the rivets or from our neglect of certain factors which enormously increase the resisting power of the rivets, such as the friction between the surfaces in contact due to the grip of the rivet on cooling. Here, again, the tests should have a two-fold object, viz., ascertaining the stress which the rivet actually bears, and the stress which it is capable of bearing without failure.

The author would like to impress this two-fold principle on all engineers who are carrying out tests on compound structures, whether for the purpose of measuring impact stresses, static stresses or secondary stresses. To make their information complete, two things are needed, (*a*) a measure of the ultimate resistance of the assembled structure and of its component parts respectively, (*b*) a measure of the stresses produced by different types or arrangement of loads whether static stresses, impact stresses, secondary stresses or temperature stresses, &c. If this point appears to be unduly pressed, the author craves pardon on the grounds that it has appeared to him that although there has been great discussion in the technical press regarding the stresses which may be expected in bridges from impact and other causes, there has been little reference to the maximum stresses which the structures will ultimately carry, and so far as riveting is concerned, it is obvious that the latter are far higher than those commonly considered to be the ultimate breaking stresses.

To measure the precise factor of safety of a particular bridge, it is necessary to know not merely the actual stresses under speed conditions, but also the maximum load which the bridge will carry without failure. No experiments have been carried out to ascertain the latter figure, and therefore some of the discussions regarding the exact amount of the impact effect in bridges are rather artificial.

*Problems arising out of Railway Amalgamations.*—Railway engineers in this country have never been bound by absolute rules concerning the design of steel bridges similarly to engineers in European countries and in India, where bridge rules are imposed on them either by law, edict or rule of a Railway Board. Their practice has therefore varied, and as a result the standards of strength adopted on the many independent systems in existence to-day are by no means uniform.

One effect of the impending amalgamations will be that the chief engineer of a group of railways will have seriously to consider the adoption of a consistent system on the grounds of economy; since having decided upon a reasonable factor of safety for new bridges as well as for existing ones, any increase in this factor will involve a waste of money, and any decrease an increase of risk, neither of which can be justified.

Every means should therefore be adopted to ascertain the real resisting capacity of existing types of bridge, the problem being, of course, rendered more urgent by the probable increased interchange of locomotives and rolling-stock.

Since economy is to be the principal aim in future railway management, even more so than in the past, economy being the *raison d'être* of amalgamations, no bridges will have to be prematurely removed, and the factor of safety will not be put at an unduly high figure. This demands a more accurate knowledge of the stresses in structures than is at present obtainable, and the author would urge all bridge engineers to consider the best methods by which a better knowledge can be obtained.

All outstanding problems of design, of economical types of bridges, and other vexed questions, are affected by our defective knowledge of the action of complex structures under load, but one may be confident that the growing appreciation of the importance of scientific research into these questions will, within the next few years, add greatly to our store of information and enable more economical structures to be built. At the same time the great attention which is now paid to durability should render the task of the maintaining engineer of the future a much lighter one.

* Paper read before Section G of the British Association at Hull, September 7, 1922.

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GERMAN TRADE WITH JAPAN.—Indications of Germany's rapid recovery from the war may be seen in her trade relations with Japan, says the *Iron Age*, New York. Imports by Japan from that country have been so heavy lately that Japanese manufacturers are complaining and seeking protection. German products, they state, are selling at prices lower than the Japanese market, especially in steel, machinery and dyes; German steel exports to Japan are showing up well, whilst America's exportation is on the decline, and Great Britain's record is slightly better than in the previous year.

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THE GLOW-WORM AS AN ILLUMINANT.—Research on the fire-fly by Dr. Herbert Ives recorded in a recent issue of the *Journal of the Franklin Institute*, has a curious interest. Determining the luminous emission of the glow-worm the larva of the fire-fly by the usual photometric method, Ives found that the luminous emission of the insect is 0·0144 lumen per square cm., whilst the figure for the bright sky is 1 lumen and for a tungsten lamp 500 lumens. The remarkable feature is, however, that the glow-worm light is all confined to the yellow-green between 5,600 and 6,700, that is, to the most luminous part of the spectrum; its luminous efficiency, determined by several methods, was above 80 per cent., whilst the luminous efficiency of the carbon lamp is ½ per cent. All our illuminants give a little light in addition to a great deal of heat; the glow-worm produces a "cold" light, practically without heat, and that light is monochromatic.

## PETROL-DRIVEN RAIL CARS.

THE petrol-driven rail motor car is a logical development of the steam motor coach which was first introduced into this country to provide increased facilities for a patronage which did not warrant a frequent normal train service. The petrol car in its present form is a rather smaller unit than the steam motor coach, and in American and Canadian practice has been developed more along the lines of an omnibus type of vehicle. The manufacture of these cars has recently been taken up by Messrs. Leduc and Jennings, Limited, of Montreal, both passenger and freight models being manufactured, of which we give illustrations in Figs. 1 to 4 herewith.

Operated by one man, running expenses of these cars in practice are as low as 11 cents per car-mile, compared with 1 dol. 50 cents to 1 dol. 75 cents per train mile for steam-driven trains. This low cost of operation, together with their notable utility in sparsely-populated districts, form their chief claims to recognition. Another point in their favour is ease of manufacture, for these petrol railway cars can be assembled largely of standard fittings and equipment, which contributes considerably to low first cost.

With a possible speed of 50 miles an hour in practice under Canadian regulations these cars are not allowed to exceed 40 m.p.h. Two sizes have so far been made by the Montreal firm, viz., for 20 and 32 passengers, of an overall weight of 9 tons and 10 tons respectively. At a speed of 20 m.p.h., they can be readily stopped by the hand brake in three car lengths. In service in Canada the smaller model has attained an average petrol consumption of 14 miles to the gallon. Its light weight and practical design are responsible for this low petrol consumption. The first cars manufactured in Montreal are in use on the Canadian National, the Canadian Pacific and the Quebec Central Railways. One has also been supplied to the Delaware and Hudson Railroad, for use between St. Lambert and other Quebec provincial points, and is reported also to be giving satisfaction. The Canadian Pacific Railroad is using its first petrol-driven car for suburban work, from Cote St. Paul in the industrial heart of Montreal to Highlands, a new suburb on the banks of the St. Lawrence, a run of about 5 miles. The petrol car is particularly useful on such a route, Highlands being a quite new and, as yet, little developed section whose transportation needs are well met by a general utility car which carries both passengers and baggage.

The first model made by Messrs. Leduc and Jennings, Limited, was for 20 passengers. On the line on which it was first used it showed a petrol consumption of 7 miles to the gallon. It operated with satisfaction on this route during summer months, but had subsequently to be moved to a New Brunswick route where the winter snows were not so heavy, nor the drifts so deep. On this second route it has operated through winter and summer for over a year, covering a daily distance of 100 miles. It was fully able to negotiate the smaller snow-falls in the latter district, and went through the winter without mishap.

In the larger model there are two designs, one for 32 passengers only, the other for 30 passengers. The latter is convertible, having a front compartment with removable seats in which baggage or freight can be carried. When put to this use it carries 22 passengers in its rear half. In accordance with regular Canadian practice, the car is provided with a lavatory compartment. The illustrations, Fig. 1, shows the all-passenger type, while the freight-carrying design is illustrated in Figs. 2, 3 and 4. From these it will be seen that the body dimensions are 23 ft. long by 8 ft. 6 in. wide, and 10 ft. 3 in. high. The wheel base is 18 ft. between truck centres. The car is mounted on two four-wheel trucks, the rear wheels being coupled, and the drive transmitted to the rear bogie by means of a long transmission shaft from the engine under the bonnet in front.

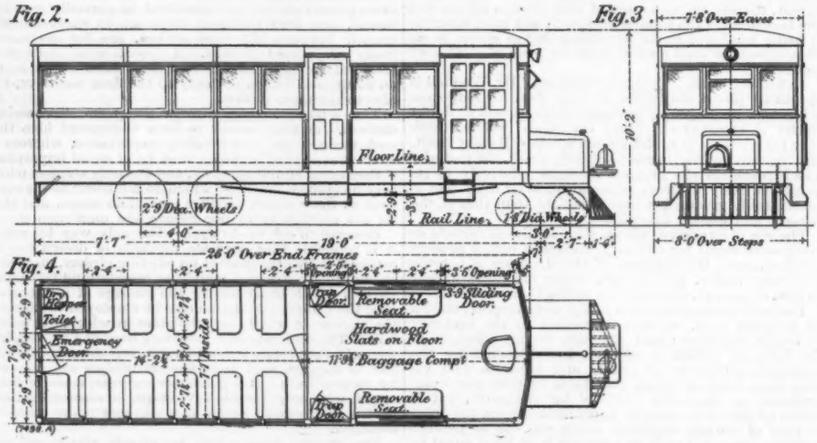
The axles, which are all alike, and are solid chrome-nickel, heat-treated steel, 3 in. in diameter. The springs are 40 in. long and 3 in. wide, with 18 leaves $\frac{1}{4}$ in. thick. The capacity of the springs is 5,000 lb. each. Standard railway brake shoes are used on all eight wheels operated by hand by what in a motor car would correspond with the steering wheel, but in this railway car is the brake wheel. The brakes are applied through bevels and chain wound on a shaft. The under-frame is of 7-in. channels, reinforced with the usual fish belly railway construction in the centre.

The engine unit, as Messrs. Leduc and Jennings point out, can be whatever is desired. So far the pattern adopted has been the Canadian-built engine of the Reo Motor Car Company, Limited, St. Catherines, Ont. This motor is a six-cylinder four-cycle engine, with cylinders and upper half of the crank-case cast integral and with removable cylinder head. The bore is $3\frac{1}{16}$ in., stroke 5 in., and S.A.E. rating 24·3 h.p. The actual power developed is 50 h.p. at 2,000 r.p.m. The crank-shaft is of high manganese steel, heat treated, ground and balanced. The removable main bearings are

# PETROL-DRIVEN RAIL CARS.

CONSTRUCTED BY MESSRS. LEDUC AND JENNINGS, LIMITED, ENGINEERS, MONTREAL.

FIG. 1.




of bronze, babbit lined, 2¼ in. in diameter. The connecting rods are light, heat-treated I-section drop-forgings. The pistons are of special aluminium alloy, with three two-piece high duty rings. The oil pan is removable for adjustment of bearings or withdrawal of pistons and rods. The valves are of the poppet type, with exhaust to the side and inlet in the head. Detachable heads are fitted for valve grinding and removal of deposit.

Lubrication is by combination force feed from submerged plunger pump to main bearings, cam gears and inlet valve mechanism, and splash to cylinders and connecting rod bearings. The clutch is of the dry disc type, with 13 plates, and 7 plates asbestos-lined. A fabric disc universal joint is arranged between the clutch and gear-box, which is of the sliding selective type, giving three speeds forward and one reverse. The gears have a $\frac{1}{4}$-in. face and are case-hardened. Hyatt roller bearings are fitted throughout. The drive is of Hotchkiss type, the thrust and torque of the axle being taken through the front half of the rear springs. The driving shaft is of heat-treated high-carbon steel with two universal joints. The shaft universal is, as already stated, of the fabric disc type. The gear reduction from the engine to the rear wheels is, in top speed 4·7 to 1, second speed 8·4 to 1, low speed 17·3 to 1, and reverse 23·5 to 1.

Cooling is by positive water circulation by a gear driven centrifugal pump, with flat vertical tube radiator provided with an air fan. The petrol tank capacity is 30 gallons, while 3½ gallons of water, and 7 quarts of lubricating oil are carried. Electric starting and lighting equipment is also provided. For winter, the exhaust from the motor is used to heat the car, which also is fitted, as is essential in Canada, with double windows throughout for winter use.

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SHEATHED AND SHEATHLESS WIRES FOR IRON WELDING.—When the material, which is to unite the two parts to be welded, is supplied in the shape of a wire, the wire is sometimes provided with a cover or sheath which is to deoxidise or to form a protective slag. In the process of the Swedish engineer O. Kjellberg, this sheath consists of refractory material (magnesia and chalk and, further, a chemical binding or purifying agent, titanium, or magnesium) which is to melt less rapidly than the wire, and which therefore forms a temporary cup for the fused iron of the wire. In comparative tests on the Kjellberg process, Dr. Ing. C. Diegel (*Stahl und Eisen*, August 29) found that the sheathed Kjellberg wires came out worst, especially with electric welding, though the welds as such looked very good. The sheath did not appear to offer any advantage, and the electric welding appeared rather to increase the absorption of nitrogen which favours brittleness.

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NEW ASSISTANT ENGINEER-IN-CHIEF.—Engineer-Captain William Rattey, C.B., O.B.E., who has begun duty as Assistant Engineer-in-Chief of the Navy, has for the past three and a-half years been Fleet Engineer Officer on the Staff of Admiral Sir Charles Madden in the Queen Elizabeth. He was the first engineer of the ill-fated battle cruiser Queen Mary, lost at Jutland, but was transferred from her in April, 1915, to the battleship Revenge, which also fought at Jutland. Awarded the O.B.E. in July, 1919, for his Grand Fleet service, he was also decorated with the C.B. in the last Birthday *Gazette*. This is the fourth change in the Engineering Department at the Admiralty which has occurred recently, as in June, Engineer Vice-Admiral Robert B. Dixon, C.B., became Engineer-in-Chief, Engineer-Captain W. M. Whayman, C.B.E., Deputy Engineer-in-Chief, and Engineer-Captain L. J. Watson, O.B.E., junior Assistant Engineer-in-Chief.

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MALAYAN WOODS.—The forest authorities of the Federated Malay States are giving the users of commercial woods an opportunity of becoming acquainted with the products of the Malayan forests. A few cabinets of samples have arrived at the offices, 88, Cannon Street, of the Malay States Information Agency, where they may be seen and purchased. Each cabinet contains 70 samples. Each sample is named and initialled by Dr. F. W. Foxworthy, Forest Research Officer, F.M.S. They are smooth but unpolished, and it is thus possible to appreciate the grain of the woods and to judge their suitability for cabinet or other woodwork. A full description of the woods is given in Dr. Foxworthy's bulletin, "Commercial Woods of the Malay Peninsula," also obtainable at the agency. Tables show the specific gravity of the various woods, as well as the dry weight and seasoned weight in pounds per cubic foot, and a chapter is devoted to the possible uses of the woods under varying conditions.

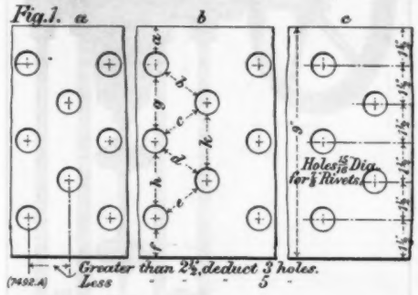
# THE INFLUENCE OF RIVET HOLES ON STEEL STRUCTURES.

*The Influence of Rivet Holes on the Strength and Endurance of Steel Structures.**

By J. S. WILSON, A.C.G.I., Assoc.M.Inst.C.E., and Professor B. P. HAIGH, D.Sc., M.Inst.C.E.

IN bridges and other steel structures, the members are joined together with rivets and are built up of plates, angles and other rolled sections riveted together along their whole lengths. Members in tension are obviously weakened by the numerous rivet holes that reduce the transverse sectional areas, but the ratios of reduction are not at present well established. The problem is of great importance to bridge and structural engineers, and is of scientific interest on account of its bearing on the theory of stress-distribution in relation to "fatigue" in metal.

In the opinion of the authors, current bridge designing practice has been influenced to an undue degree by conclusions drawn, directly or indirectly, from the results of "static" tests in which typical members have been tested to destruction under steady loads. Although



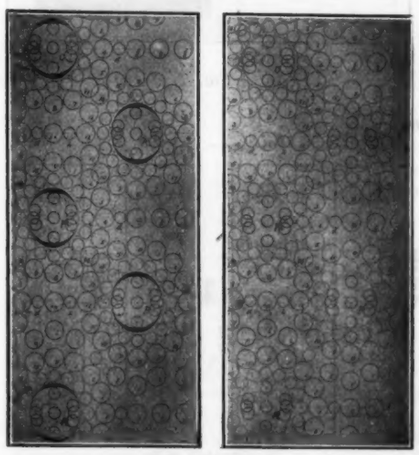



FIG. 2. STRAINED. FIG. 3. UNSTRAINED.

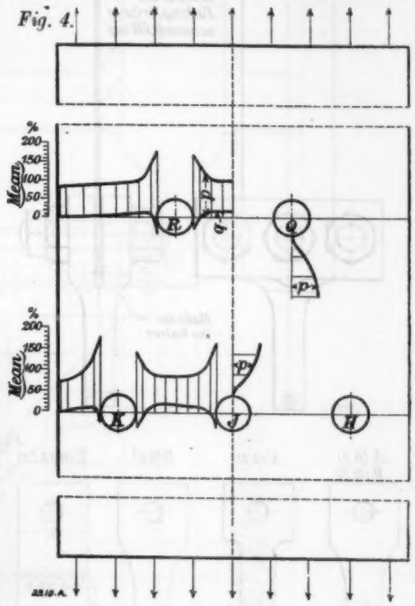
experience has shown that the breakages that occur in practice are due to cracks produced by moderate stresses varying with the loads on the structure, experiments have not hitherto been available to show the action of such stresses on structural details. It appears to the authors that designers, lacking the support of data from experimental sources, have neglected lessons that might have been drawn from practical experience and have yielded to a tendency to exaggerate the dangers of "live loads."

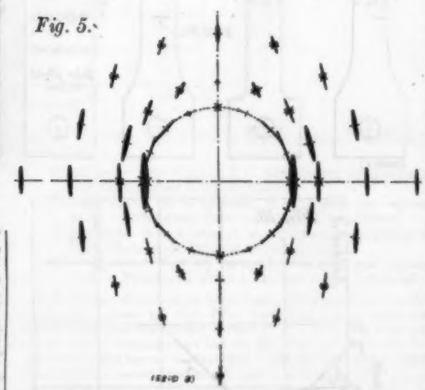
A distinction is now widely recognised between the "ultimate" and "fatigue" strengths of metals, as determined by tests on simple bars without perforations or other irregularities of profile. Whereas the "ultimate tensile strength" measures the load required to cause fracture when that load—acting as tension—is steadily increased, the "fatigue limits" measure the much smaller stresses which—being applied and removed repeatedly, or reversed or otherwise varied in cyclic manner—eventually result in failure by the development of cracks, without that elongation which is so characteristic of the ordinary tensile test. In stresses that alternate between equal intensities of pull and push, the fatigue limit varies from 30 per cent. to 60 per cent. of the ultimate strength, and is usually about 45 per cent. in steels suitable for structural purposes. The ratio is independent of the frequency of alternation, but varies with the relation between the extreme stresses in the cycle as discussed later. For perforated sections, however, the ratio does not directly indicate the relative strengths of the section under steady and alternating stresses.

* Paper read before Section G. of the British Association at Hull, September 7, 1922.

In practical design, allowances are made for the reduction of strength due to rivet holes; and these allowances, by increasing the cross-sectional areas of the members, add to the weight and cost of the structure. To minimise these additions, the designer often staggers the rivet holes so that fewer holes come on a transverse section, and avails himself of the sanctions given by more or less arbitrary formulæ based, presumably, on ultimate strength tests. The lack of information on the subject, as revealed in text books and designing specifications, leaves the matter in an unsatisfactory state. The authors know of only two rules used for the purpose. One rule is to the effect that if the longitudinal pitch between the rows of staggered rivets is less than about 2½ in. (the figure varies slightly), then all holes must be deducted in getting the net sectional area. Fig. 1 (*a*) represents the practical application of this rule; its arbitrary nature is sufficiently indicated by the fact that no reference is made to the diameter of the rivet holes. A second rule, which will be found in Mr. Theodore Cooper's designing specification, is given as follows:—

"The rupture of a riveted tension member is to be considered as equally probable, either through a transverse line of rivet-holes or through a zig-zag line of rivet




holes, where the net section does not exceed by 30 per cent. the net section along the transverse line." This is usually interpreted as follows (see Fig. 1 (*b*)):—

If $(a + b + c + d + e + f)$ is greater than $1{\cdot}30\ (a + g + h + f)$ . . . . . (I)

or $(a + b + k + e + f)$ greater than $1{\cdot}30\ (a + g + h + f)$ . . . . . (II)

then in the case illustrated only three holes need be deducted, otherwise five holes must be deducted. It will be recognised that there may be a considerable difference between (I) and (II), and the rule is not definite as to whether rupture anticipated by (II) should be considered. With the dimensions given in Fig. 1 (*c*), about 1⅞ in. would be the critical pitch for (I) and 2½ in. for (II).

As a result of a lack of a generally accepted rule or principle for estimating the net sectional area of such riveted members, it frequently happens that the tensile stresses, which should agree, often differ widely when taken out by different individuals; and allowances made in practice for the rivet holes are frequently excessive.

This point has an important bearing on the tests carried out by the Ministry of Transport with the object of amending the Board of Trade Requirements in regard to Railway Bridges. The measured stresses given in the report were obtained by measuring the extensions under working test conditions of various bridge members, most of which were under tensile stress. These are compared with calculated stresses, but in deducing the various stresses the method of allowing for the rivet holes is not indicated.

From the theoretical point of view, the problem of fatigue in perforated plates is dominated by two outstanding considerations as follow:—(1) The distribution of stress across a section that passes through a perforation in a plate is far from uniform, the stress values near the opening being much greater than those at a distance, and therefore greater than the nominal mean value. At points where the stress tends to exceed the yield-point, permanent strains are produced by the metal yielding. (2) Except in the extreme case in which the areas subject to such stress concentrations are small in comparison with the grains of the metal, as exhibited in its micro-structure, the incidence of fatigue depends on the range of stress that occurs in the areas subject to concentration—not directly on the mean stress on the section.

It may be observed that the above conclusions are fully borne out by common experience in connection with high-speed machinery, showing that fatigue cracks generally start from discontinuities of profile and thence spread across sections on which the mean stress may be comparatively low.

In certain simple cases, the local concentration of stress round an opening may be investigated mathematically and the conclusions hold rigorously when the stresses lie wholly within the elastic range. Thus Dr. Suyehiro* has shown that for a circular hole in a plate of unlimited width the greatest stress occurs on a transverse diameter and is three times the mean intensity, and Prof. Inglis† has extended mathematical analysis to a variety of other openings.

The most common form of perforation in steel structures is, of course, the circular hole which is more or less perfectly filled by the rivet. The exactitude of fit and the proximity of adjacent holes unquestionably affect the distribution of stress, and present conditions too complex for mathematical treatment.

Local concentrations of stress may be deduced also from experiments on elastic materials, and one of the authors‡ helped to measure these stresses in an exact representation of the filled rivet hole of practice. A number of holes were made in a slab of rubber (9 in. wide, ⅜ in. thick), and accurately plugged with the same material. When slightly stretched the distortions were measured and from them the stresses deduced. Figs. 2 and 3 are photographs of the rubber surface strained and unstrained, and show the distortions. The results are represented in Figs. 4 and 5, and show that the maximum longitudinal stress $p$ at the sides of the holes is nearly double the mean stress. It will be noticed that owing to the hole being filled, this longitudinal stress is accompanied by a transverse compressive stress $q$. In cases of complex stress distribution it would be extremely helpful if the stress conditions could be completely represented in a diagram, but this seems impossible; in Fig. 5 the ellipses of stress are drawn and give the magnitudes and directions of the stresses at different points round one of the rivet holes, but this more complete representation of the stress conditions does not give a very clear impression.

Many other cases, including plates with circular perforations have been investigated by Professor Coker§ using perforated strips of celluloid and polarised light for determining the stresses.

In cases that can be compared, the results obtained experimentally agree with the conclusions drawn from mathematical investigation, and the experiments on groups of holes show that when a number are pitched on a transverse section the maximum stress concentration is less than the three-times mean value applicable to a single hole in a wide plate, and depends on the ratio of the diameter to the pitch.

If these stress concentrations due to perforations seriously increased the liability to fatigue, only very moderate stresses could be used in practice. For instance, assuming that the steel used in a perforated member were of 30 tons per square inch ultimate tensile strength, and that its fatigue limit for pulsating unidirectional stress were 40 per cent. of this, say, 12 tons per square inch, then if the stress concentration ratio were as great as 3 : 1, fatigue would be inevitable if the mean stress pulsated from zero to 4 tons per square inch, and fracture would be probable under much lower stresses if the axial load were associated with any bending. It may be stated at once that this supposition is not supported by the results of the experiments to be described.

The experiments were carried out on model plates, 1½ in. wide and $\frac{1}{16}$ in. thickness, 6 in. in length, with and without perforations, as illustrated in Fig. 9 and detailed later. These dimensions were adopted to suit the testing facilities available, and to reproduce the proportions found in a typical full-size plate in a bridge member, 9 in. by ⅜ in., with $\frac{13}{16}$ in. holes to suit ⅞-in. rivets. To simplify the preparation of the test-pieces the holes were not plugged, but in later experiments the authors hope to investigate the influence of the rivets.

The experiments were carried out in a Haigh alter-

* ENGINEERING, September 1, 1911, page 280.

† Trans. Inst. Naval Architects, vol. 55, page 219.

‡ Trans. Inst. of Naval Architects, April, 1911, experiments by Wilson and Gore described in discussion on Professor Coker's paper. Also see ENGINEERING, April 21, 1911, page 531, and September 19, 1913, page 385.

§ Cantor Lectures, Royal Society of Arts, 1913.

nating stress-testing machine, a full description of which has been published.*

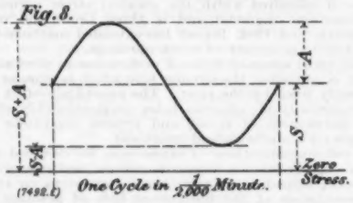
The machine was adjusted to apply pulsating tensile stresses and was operated in all the tests at a frequency of 2,000 stress cycles per minute. It may be noted, however, that other experiments have shown that the frequency of pulsation does not, within wide limits, appreciably influence the results of such fatigue tests.

Figs. 6 and 7 show the method of securing the test-pieces in the machine. The test-plates were drilled at the ends and clamped between accurately-fitted sheet brass packings in the steel jaws. These had screwed shanks to suit the testing machine. The test-pieces were pulled vertically, the upper end being held stationary in the fixed but adjustable head of the testing machine while the lower end was pulled and released with variable tension. The machine is fitted with an automatic cut-out that switches off the operating current as soon as the elongation of the test-piece exceeds a predetermined value; so that the test would be stopped as soon as a crack opened and before fracture caused complete severance. Considerable care was taken to achieve axial loading. The end holes were put accurately on the centre lines of the test-pieces and the grip bolts were screwed up when each test-piece was in place in the machine and supporting an initial load.

Fig. 8 represents the cycle of stress, a sine-wave; and the conventional symbols used to define the magnitude of the stresses. The tension varied from a maximum $(S + A)$ to a minimum $(S - A)$; and in the tests in question the latter did not reverse into compression.

The mean tension value S will be termed the "steady component stress"; and the semi-range of tension A, the "alternating component stress." The two components S and A can be adjusted independently in the testing machine, and in the usual method of testing are maintained at predetermined values throughout the duration of a test. When the test-piece eventually breaks, after the application of a great number of cycles, the machine automatically records the "endurance" N, usually measured in millions of cycles. The report of a test on any given test-piece states three variables, viz., S, A and N.

Fig. 8.




The steel used in the fatigue experiments was of a very mild quality and gave tensile tests (under steady loads) as follow:—

| Sample Number. | I.1. | II.1. |
|---|---|---|
| Yield-point, tons per square inch ... ... ... | 13·0 | 12·75 |
| Ultimate strength, tons per square inch ... ... | 22·65 | 22·0 |
| Elongation on 3 in., ¾ in. wide, per cent. ... ... | 22·4 | 22·7 |

The sample numbers I and II refer to the separate plates from which test-pieces were cut. The two are nearly alike in quality, and the yield-point is 57 per cent. to 58 per cent. of the ultimate tensile strength.

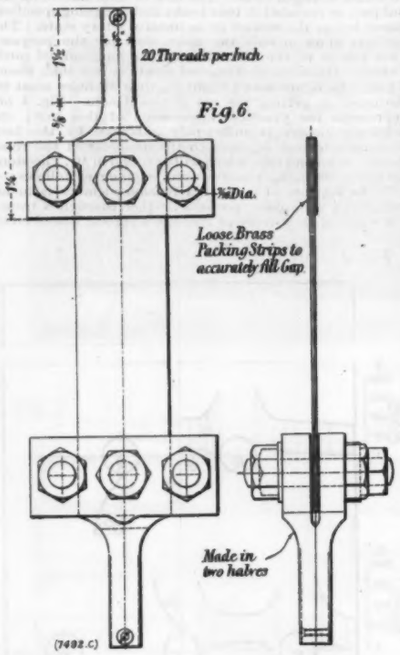
It is considered that the comparatively low value of this ratio (yield/ultimate) had an important influence on the results of the fatigue tests, and that the same influence has a similar helpful effect in engineering structures. It had been intended originally to supplement the investigation with experiments on a high-tensile steel with a higher value of this ratio, but these experiments have been interrupted.

The influence of the yield/ultimate ratio upon the liability to fatigue, from the standpoint of established theory, is as follows: Fig. 10 represents to scale the general fatigue properties of the 22-ton steel in question. The base line represents different "steady component stresses" S used in fatigue tests, or the steady stresses applied in tensile tests; thus Y represents the yield-point and U the ultimate tensile strength. The ordinates represent the "alternating component stresses" A, applied in the fatigue tests. Any point in the diagram, with co-ordinates S and A, represents the combination of stresses applied in a particular experiment. The line Y Y′, whose equation is $S + A = Y$, may be described as the "yield line"; thus the steel yields when the maximum stress, equal to $(S + A)$ exceeds the yield-point Y. In any fatigue experiment the stress point must be kept below this yield line, since otherwise the metal will yield before fatigue can develop. For the thin plates used in the experiment buckling would occur if the minimum stress $(S - A)$ became compression. Hence, as a second limitation in this instance the stress-point must be kept below the line O Z, whose equation is $A = S$. Combining these two theoretical limitations, based on the yield stress and non-reversal, we see that the stress point must keep within the 45 deg. isosceles triangle O T Y, of which the apex T is the intersection of the loci O Z and Y Y′ which run at right angles to one another.

For a low tensile steel such as that used in the experiments, it may further be assumed that the "basic" fatigue limit is about 45 per cent. of the ultimate strength, say, 10 tons per square inch $= A_0$: That is, when $S$ = zero, fatigue can occur only if A exceeds this value $A_0$. This point, marked on the axis of the diagram, is joined to the ultimate strength point U by two graphs —the one a parabola $A_0$—Gerber—U, and the other a straight line, $A_0$—Goodman—U. According to Gerber and to Goodman respectively, fatigue can occur under different combinations of S and A, only when the stress-point lies above the one or other locus respectively.

* *The Engineer*, July 29, 1921.

Fig. 6.



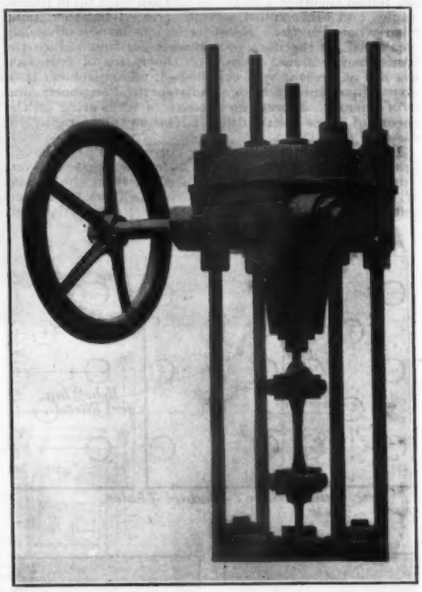



FIG. 7.

Fig. 9.

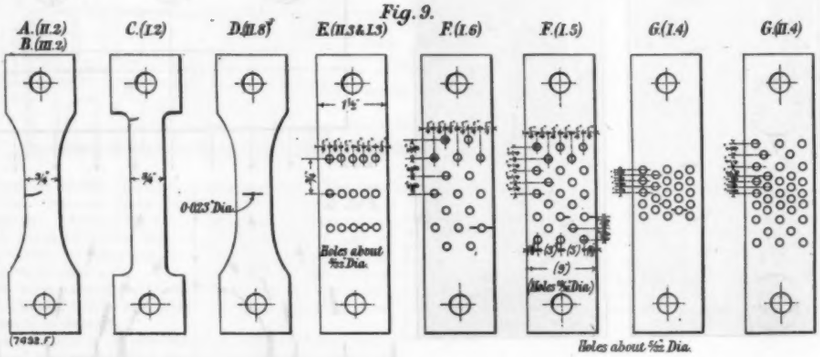



Fig. 10.

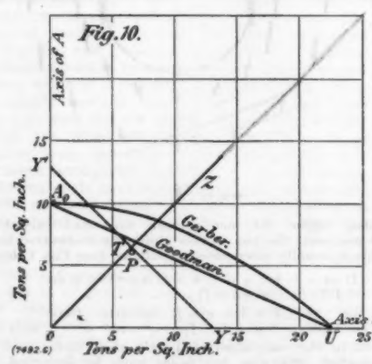
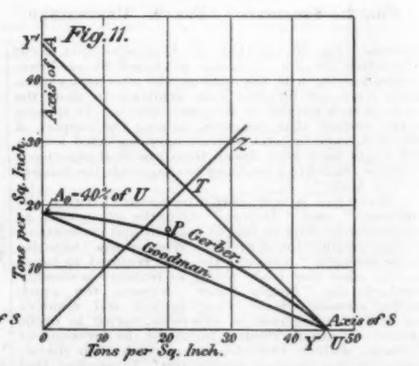



Fig. 11.




Thus the metal is liable to fatigue when, and only when,

$$A > A_0 (1 - (s/u)^x)$$

where the index $x$ is to be taken as 2 according to Gerber, or 1 according to Goodman.

It will be observed that in the scale diagram Fig. 10, even the Goodman locus lies wholly above the triangle O T Y, indicating that fatigue should not occur under the limiting conditions explained above. The Gerber locus lies still further above this limiting triangle; and accumulated evidence* indicates, at least for mild steels, as used in practice and in this investigation, that the Gerber locus is the more correct of the two. It appears therefore, improbable that fatigue can occur under stresses within the yield range, unless these stresses reverse in direction—acting as pull and push alternately. This conclusion has been verified in an experiment (A), described below, using metal with a low value of the "yield/ultimate" ratio; and a further experiment (B) on steel with a high value of this ratio, serves to limit the sphere of application of the conclusion.

*Experiment A* (II.2).—This experiment was carried out to ascertain whether fatigue could occur in steel having a low "yield/ultimate" ratio when subjected to unidirectional stresses of magnitudes suggested by the foregoing theoretical considerations.

The test-plate was 1¼ in. in width, narrowed to ¾ in. for a length of 1 in. in the middle, and joined to the ends by smooth transition curves such as would cause no appreciable concentration of stress (Fig. 9, A). A fatigue test was made with $S = 6\frac{1}{2}$ tons and $A = 6$ tons per square inch, as represented by the point P (Fig. 10) just below the apex of the limiting triangle. After

* Haigh, Brit. Assoc. Report of Stress Committee, 1914.

2·852 million cycles of stress the test-piece was still unbroken. The steady component was then increased to 7½ tons per square inch, giving a maximum of 13½, and it was found that the test-piece yielded slowly but steadily.

Referring to Fig. 10 it will be seen that the increase in S from 6½ to 7½ puts the stress point just above the yield line TY. Thus the non-occurrence of fatigue in the first test, and the occurrence of yield without fatigue in the second, are both in agreement with the theory given above.

*Experiment B* (III.2).—To show that in steel having a high "yield/ultimate" ratio, fatigue may occur under unidirectional stresses that do not suffice to cause elongation by yielding.

A test similar to the above (Fig. 9A) was carried out on a sample of cold-rolled steel with Y = 45·5, U = 46·1 tons per square inch*, corresponding to a ratio Y/U of nearly 99 per cent. In this case the apex point T is given by S = A = Y/2 = 22·7 tons per square inch. A fatigue test was made with S = 20 and A = 16, well within the triangle O T Y (Fig. 11) and it was found that the test-piece grew quite warm and fractured after only 60,000 cycles of stress. The contrast between Figs. 10 and 11 and the different behaviour of the two steels may be explained in the first place by the fact that the triangle O T Y for the harder steel is relatively larger than for the soft one on account of the high ratio Y/U; and in the second place by the Goodman and Gerber lines being relatively lower for the hard steel because the ratio $A_0/U$ is usually lower than the 45 per cent. value assumed for the mild steel.

*Experiment C* (I.2).—To show that fatigue may occur in steel with low yield/ultimate ratio, subjected to unidirectional stresses, when the profile is arranged to produce moderate local concentration of stress. The test-piece used had a parallel mid-length, ¾ in. wide, joined to the 1½-in. ends with circular fillets of $\frac{1}{16}$ in. radius. A fatigue test was made with S = 6½ tons per square inch, reckoned on the ¾-in. width. When the alternating stress component A was raised to 6½ tons per square inch, corresponding to a maximum stress of 12¾, slight but definite elongation was observed; and A was therefore reduced to 6, giving a range of stress from 12½ tons to ½ ton per square inch. After 524,000 cycles a fatigue crack opened where the fillet joined the parallel part of the test-piece.

The effect of the stress concentration on the result may be explained by reference to Fig. 12. Under moderate stresses within the elastic range the influence of the fillet is to distribute the stress with a peak at the edge as shown by curve *a*; but with greater loading, when the intensity at the peak tends to exceed the yield-point as at *b*, the metal would yield locally and the distribution of stress would follow some curve like *c* with a maximum intensity equal to about the yield stress. With all the load removed, the metal at the edge which had been permanently stretched would be drawn into compression by the rest of the metal which had not been stressed beyond the elastic limit, and the distribution would be as at *d*. Repetition of the same loading would under the circumstances produce reversing stresses in the zone near the edge and render it more liable to fatigue.

This same experiment serves to illustrate the remarkable difference between results produced by steady and varying loads respectively. Whereas, in a tensile test, the specimen would have drawn out and broken about mid-length, not at the fillet, the action of varying stress is to produce a crack at the shoulder.

*Experiment D* (II.8).—To test the stress-concentration effect, under conditions more comparable with theory. A test-plate shaped as in experiment A, and ¾ in. wide at mid-length, was prepared, and a small hole 0·023 in. diameter drilled in the centre line (Fig. 9D). Thus the specimen approximately fulfils the conditions for giving a 3 : 1 magnification of stress at the margin of the hole, on a transverse section.

Four consecutive tests were carried out with different ranges of stress, and it stood the number of repetitions as follows :—

First test : S = 5 tons, A = 4½ tons per square inch. Unbroken after 5·690 millions.
Second test : S = 5½ tons, A = 5 tons per square inch. Unbroken after further 2·976 millions.
Third test : S = 6 tons, A = 5½ tons per square inch. Unbroken after further 2·768 millions.
Fourth test : S = 6½ tons, A = 6 tons per square inch. Fractured after a further 0·998 millions.

It had been anticipated that fracture might occur under moderate stress in the first test, but the experiment shows that the maximum stress (S + A) = 12½ tons per square inch, required to induce fatigue, is but little less than the yield stress of the steel—13 tons per square inch. It should be noted that the S and A values quoted above are calculated on the gross cross-section, 0·750 in. by 0·0615 in., without any allowance for the hole or stress-concentration effects.

The cracks started from the sides of the hole and ran outwards at right angles to the axis of stress, as shown in Fig. 9D.

To ascertain whether the discrepancy might be attributed to the comparatively small size of hole used in the experiment, the metal was examined under the microscope (Fig. 13). It was found that the structure, as might be expected in a steel giving such a tensile test, was of ferrite grains enclosing particles of cementite in groups. The linear dimensions of the larger grains ran from 2 mils. to 4 mils. and were small in comparison with the diameter of the hole, 23 mils. The photograph shows the structure at 500 magnifications; and, on this scale, the hole would appear nearly 1 ft. in diameter. The relatively slight influence of the stress-concentration cannot be attributed to any approximation between the size of the grains and of the opening.

The result of this test is remarkable, for it clearly shows that the effect of the stress concentration on fatigue in a test specimen of this kind is much less than might be anticipated.

*Experiment E* (II.3 and I.3).—As shown in Fig. 9E, these two test-plates were pierced with three rows of five holes, 4 mm. diameter, making the net width only about half the full width of the 1½-in. plate. The stresses quoted below are calculated on the residual net width of the necks between the holes, or holes and edges, as measured by a sensitive micrometer-microscope. The measurements for plate II.3 are as follows :—

First row : 3·70 + 2·36 + 2·22 + 2·30 + 2·30 + 4·29 = 17·17.
Second row : 3·88 + 2·58 + 2·29 + 2·43 + 2·31 + 4·00 = 17·49.
Third row : 4·20 + (2·36) + (2·36) + (2·33) + (2·30) + 3·95 = 17·50.

(The dimensions are in millimetres.)

The figures in brackets in the third row are the widths of the necks that cracked in this test with S = 7 tons, A = 6 tons per square inch, after 1,224,000 cycles. The maximum (S + A) stress applied in this long-continued run was 13 tons per square inch, equal to the yield stress of the metal, but only a slight trace of yield was observed even at the start of the test.

Test-plate I.3 of almost identical dimensions was tested with S = 6·0 tons, A = 5·0 tons per square inch (11·0 tons per square inch maximum, 1 ton per square inch minimum), and was apparently undamaged after 2·578 millions of cycles. The stresses were then increased to S = 8·0, A = 5·5, giving a maximum somewhat over the yield point. Only very slight elongation was observed, and the test was continued until fracture occurred after 908,000 further cycles.

The large number of repetitions endured in these two tests indicates that the stresses imposed were little in excess of what the test-pieces could have withstood indefinitely, for when the endurance has attained about a million cycles, a slight reduction in stress greatly increases the endurance.

With perforations as arranged in these two tests, having spaces narrower than the diameter of the holes, the stress concentration would not be great, but the high stresses withstood suggest that the effect of it is small, and that the mean stress on the net sectional area is the governing factor.

*Experiment F* (I.5 *and* I.6).—The perforations used in this test and experiment and in G are shown in Fig. 9. The plates were drilled with holes in alternate rows containing two and three, and the longitudinal distances between the rows were 0·375 in. in I.6, 0·25 in. in I.5 and 0·125 in. in I.4 and II.4. The limiting case with all five holes in one line is represented by I.3 and II.3 of experiment E.

The dimensions of the full-size plates represented by these test-pieces are also figured in Fig. 9F, in brackets.

In I.5 and I.6 the net section through the three-hole plane measured 1·05 in. × 0·064 in. and the normal stresses quoted are reckoned on this section. Fatigue tests were carried out with S = 7 tons, A = 5 tons per square inch, and both plates fractured on transverse sections containing three holes. The endurances were nearly alike, viz., 534,000 cycles and 456,000 cycles.

In comparison with experiment E, in which a somewhat greater endurance was obtained with higher stresses (S = 7, A = 6), it appears that the greater transverse distance between the holes in F has appreciably increased the stress-concentration effect.

*Experiment G* (I.4 *and* II.4).—In these two tests the

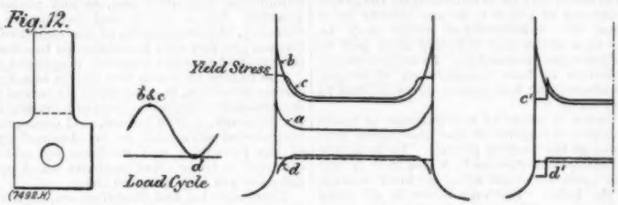



Fig. 12.

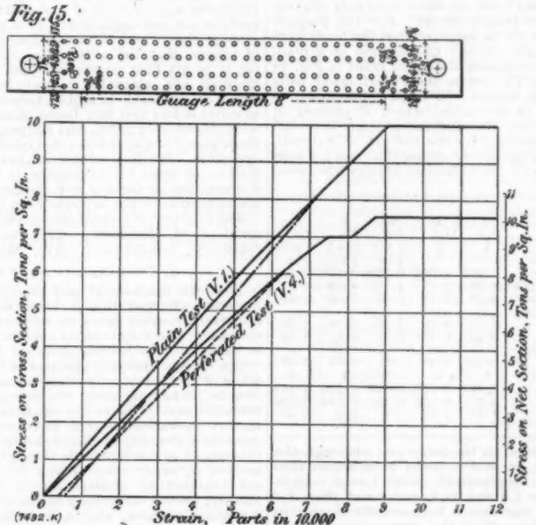

Guage Length 8"
Stress on Gross Section, Tons per Sq. In.
Stress on Net Section, Tons per Sq. In.
Plain Test (V.1)
Perforated Test (V.4)
Strain, Parts in 10,000
(7492.K)

Fig. 15.

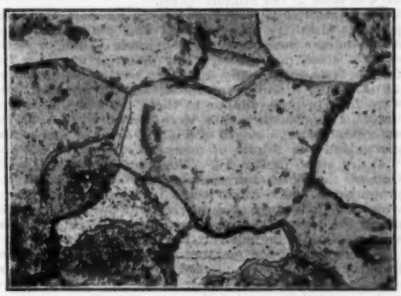


FIG. 13.

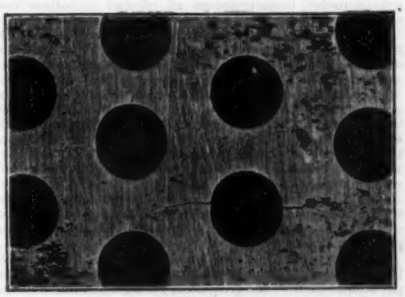


FIG. 14.

* It is interesting to note that the high loads required by this material cracked one of the grips. Messrs. Allen-Liversidge kindly repaired this by acetylene welding a new mild steel shank on to the shoulder of the grip which is made of spring steel quality. This weld has already sustained upwards of 15,000,000 repetitions of loads up to a maximum of about 800 lb.

longitudinal distance between lines of holes is 0·125 in. and the diagonal distance between holes in adjacent rows is small in comparison with the transverse distance between holes in the same row.

It was thought possible that the fatigue fracture might occur across these narrow necks as in a static test, but such was not the case.

In these experiments the loads were not proportioned to suit any particular stresses. In II.4 the loads applied to I.3 were used, namely, S = 866 lbs., and A = 595 lbs., and fracture occurred after 538,000 cycles. It is remarkable that this test failed by cracks forming in planes at right angles to the line of pull as shown in the photograph Fig. 14. As in experiment F, two cracks formed in a plane containing three holes, but in this case a third crack formed in a plane containing only two holes, a result clearly due to stress concentration. In II.4, as shown in Fig. 9*b*, the holes at the same close pitch as in I.4 had additional holes beyond at greater pitch, as it was thought that the abrupt commencement of the closely pitched holes might have introduced a disturbing effect. Lighter loads were applied to II.4, S = 815 lbs. and A = 560 lbs., and this test was unbroken after 2·164 million cycles.

*Experiment H (V.1 and V.4).*—To measure the comparative elasticity of perforated and plain bars, some extensometer measurements were made on longer pieces of mild steel, not the identical material used for the fatigue tests, but equally soft. The test-pieces measured 1½ in. wide, about ⅞ in. thick, and 12 in. long, and were held in grips similar to those used in the fatigue tests. The measurements were made with a Ewing extensometer on a length of 8 in. Details of one of the pieces and the results of measurements (tests V.1 and V.4) are given in Fig. 15. The arrangement and position of the holes correspond approximately with the proportions which might occur in a flange plate 15 in. wide with four rows of ¾-in. rivets at 3-in. longitudinal pitch, the test-pieces being one-tenth full size. Similar tests were made on unperforated strips.

The extensometer measurements reduced to strains in parts per 10,000 are plotted in both cases against the stresses calculated on the gross sectional area, and a scale is added for getting the stresses on the net area of the perforated test.

The difference in slope of the two curves proves that considerable care should be taken when converting extensometer measurements of riveted members into stresses.

In the numerous measurements of stresses recently made by the Ministry of Transport and others, the stresses are all deduced from measured extensions of members which are in most cases riveted along their whole length, and these curves enable us to check the accuracy such an estimate of stress would have in this instance. The full lines represent the first measurements on an increasing stress and the dotted ones represent the elastic lines up and down which the strains lay after the stress had been carried up to about 8 tons maximum on net area in each case.

The plain test dotted line shows that a measured strain of 4 parts in 10,000 represents an increase in stress of 4·86 tons per square inch, representing E = 12,150 tons per square inch.

The corresponding line for the perforated test shows that the same measured strain would represent 4·06 tons per square inch on the gross area, giving a stretch modulus corresponding to E = 10,150 tons per square inch; whereas on the net area the same strain represents 5·4 tons per square inch, with stretch modulus = 13,500 tons per square inch. It follows that in this instance if a measurement of 0·0004 were made and the modulus for the plain bar applied to it, the estimated stress 0·0004 × 12,150 = 4·86 would, be 11·1 per cent. less than the correct mean stress on the net area and 16·5 per cent. greater than the correct mean stress on the gross area.

In making the extensometer measurements on the perforated samples the permanent stretching under moderate stresses, caused by the stress concentrations at the holes, could be detected. This stretching, however, is necessarily small because it occurs only in a small proportion of the total length. It will be noted on referring to the curves, that the apparent permanent stretch of the perforated bar due to 8 tons per square inch maximum on the net area, is almost as great as that due to the same stress on the plain bar, although in the former the 8 tons per square inch only occurred at the necks between the holes.

*Conclusions.*—Many more tests must be made before any rule could be deduced for calculating the useful net sectional area of such perforated plates; and the authors contemplate making many more tests with that object. It will be necessary to investigate fatigue in perforated plates of steel with different values of the yield/ultimate ratio, and to contrast the behaviour of drilled and punched holes.

The holes in all tests so far have been carefully drilled, but when punched holes are tested a greater reduction in strength is expected. The influence of the rivets filling the holes must also be considerable, for practical experience shows that when, in the process of manufacture, the rivets are put into long members, a slight increase in the length of some or all of the parts often results.

In the meantime, however, it appears possible to draw certain conclusions from the tests already carried out.

Taking fatigue tests A, C and D together for comparison; test-piece A, without perforation or sharp fillets, remained unbroken after being stressed from ½ ton to 12½ tons per square inch 2·85 million times, and yielded in a ductile manner when the maximum stress was raised to 13½ tons per square inch. Test-piece C, subject to the moderate concentrations of stress caused by the fillets at the shoulders, broke after 0·32 million pulsations of stress of ½ ton to 12½ tons per square inch. Test-piece D, however, with the small hole in it giving —according to mathematical considerations—a high concentration of stress, withstood 2·76 million pulsations from ½ ton to 11½ tons per square inch, after previously having endured 8·66 millions of somewhat lower stresses. Thus it appears that D was only slightly weaker than A in spite of the high concentration due to the small hole, and that C, subject to the slight concentration, was as weak if not weaker than D.

It is remarkable that the maximum stress (S + A) in all the test-pieces that failed by fatigue, approached the yield-point for the residual metal of the net section. In these circumstances it seems impossible to avoid the conclusions that the metal adjacent to the perforations must have been strained beyond the yield-point, and that the subsequent behaviour of the steel was influenced by the property demonstrated by Professors Robertson and Cook*, that mild steel immediately after yielding continues to extend under stresses much lower than the yield point. Thus the intensity of stress near the opening or edge may be 25 per cent. less than the yield stress, and the distribution of stress may be as indicated by the graph C′ in Fig. 12, instead of graph C as has already been suggested. Thus the unidirectional stress may be changed locally to a stress that reverses from pull to push of more or less equal intensities. In such a case it might be permissible to base comparisons of fatigue strength on the alternating component stress A, and to ignore the steady stress S.

In the table below a series of comparisons is made between the relative strengths of the test-pieces perforated with holes at the various pitches. To facilitate the comparison, the applied stresses S, A and (S + A) are reckoned on the gross sectional areas without making allowances for the holes. The endurance in all cases given in the table ranged from ½ million to 1 million cycles, and the applied loads can have been only slightly above the respective fatigue limits. For the purpose of this comparison it will be assumed that the loads were actually on the fatigue limits. In the case of a plain test under such circumstances the stress point in Fig. 10 would lie on the line TY, but in these perforated tests the reduced effective section and other influences give the stresses shown in the table, which if plotted in Fig. 10 would lie below TY, and the amount they fall short would be represented by the ratio (S + A)/yield. These ratios given in the table indicate that test I.4 with ¼ in. longitudinal pitch has a fatigue strength between that of I.3 and I.5.

| | | | | | |
|---|---|---|---|---|---|
| (1) Experiment .. .. | E | E | G | F | F |
| (2) Test-piece No. .. | I.3. | II.3. | I.4. | I.5. | I.6. |
| (3) Holes in rows .. | 5 | 5 | 2 & 3 | 2 & 3 | 2 & 3 |
| (4) Pitch between rows .. | — | — | ¼ in. | ¼ in. | ¼ in. |
| (5) Endurance millions .. | ·908 | 1·224 | 0·538 | 0·534 | 0·456 |
| (6) S tons per square inch | 4·01 | 3·24 | 4·18 | 4·89 | 5·13 |
| (7) A tons per square inch | 2·76 | 2·78 | 2·87 | 3·50 | 3·67 |
| (8) (S+A) tons per square inch .. .. .. | 6·77 | 6·02 | 7·05 | 8·39 | 8·80 |
| (9) (S + A)/yield.. .. | 0·52 | 0·47 | 0·54 | 0·65 | 0·68 |
| (10) (Net section)/(Gross section) .. .. | 0·48 | 0·47 | (?) | 0·69 | 0·69 |
| (11) Holes deducted .. | 5 | 5 | (?) | 3 | 3 |
| (12) A/U .. .. .. | 0·122 | 0·126 | 0·127 | 0·155 | 0·165 |
| (13) (A/U) ÷ (0·45) .. | 0·271 | 0·280 | 0·282 | 0·344 | 0·360 |
| (14) Net/Gross section (A/U) ÷ (0·45) .. | 1·77 | 1·68 | (?) | 2·0 | 1·92 |

These ratios are given in the table and although the comparison is based on so few tests, it indicates that test I.4 with ¼ in. longitudinal pitch has a fatigue strength higher than I.3 and II.3, and lower than I.5 and I.6. The close agreement between the figures in line (9) and (10) shows that the stresses on the net sectional areas are practically on the yield point. The figures in lines (12), (13) and (14) give comparisons based on the alternating component stress A, and on the arbitrary factor 0·45 assumed as the ratio $A_0/U$ for the steel used.

Although numerous recent researches, both mathematical and experimental, in stress distribution have revealed stresses so high as to alarm some practical engineers and to provoke the blunt disbelief of others, many engineers have held that the metals used in practice have a ductility and other qualities which render them able to eliminate or accommodate those high stresses.

The experiments described in this paper not only confirm that view, but also prove that under some circumstances those high stresses, even when accompanied by permanent strains, do not appreciably reduce the strength of the metal under fatigue conditions.

* Proc. Royal Soc. A, vol. 88, 1913.

## THE BASES OF MODERN BLAST-FURNACE PRACTICE.†

By A. K. REESE, M.I.Mech.E. (Cardiff).

† Paper read at the meeting of the Iron and Steel Institute, York, on Tuesday, September 5, 1922.

IN the author's evidence before the Iron and Steel Industries Committee of the Board of Trade in 1918, he mentioned certain important features as constituting the difference between modern blast-furnace practice and such practice as is generally prevalent in Great Britain. He proposes in this paper to elucidate the reasons for those observations by outlining the bases upon which modern blast-furnace practice has been built up, and demonstrating wherein those bases supply the logical arguments for their adoption, which would lead to very desirable improvements in results, both as respects output and economy, in pig-iron production in localities where the older practice is still in vogue. There are many factors entering into this subject, each of which is more or less dependent upon the others. They may be divided under four major headings, which may be called the prime factors in modern blast-furnace practice.

Before discussing these prime factors in detail, it might be as well to consider the objects which modern blast-furnace practice seeks to obtain. That practice is distinctly the result of evolutionary progress, the modern phase dating from 1894, when James Gayley introduced the low bosh at Braddock, Pa.—up to the present, the era of the large hearth diameter and steep bosh angle. There are three principal objects in all blast-furnace practice ranking in importance in the following order—quality, economy, and quantity. The first is essential. The second is commercially of great importance. The third is highly desirable, particularly in its bearing upon the second. No. 1 may be obtained independently of the other two. No. 2 may be obtained, to a degree, independently of No. 3. No. 3 is, to a degree, subject to Nos. 1 and 2. In all blast furnaces one of these objects has been the limiting factor in the attainment of the others. The object sought through the application of so-called modern practice may be described thus:—

Consistent with quality to produce the greatest possible economical quantity; and, as any material increase in quantity has a direct and favourable bearing upon economy, this description of the object of modern blast-furnace practice may be condensed to—the attainment of the greatest possible quantity consistent with quality.

The degree to which this object has been attained in certain localities, in comparatively recent years, resulting in normal economical outputs of from 400 tons to 600 tons per 24 hours, is well known, and demonstrates the great commercial advantage to be obtained by the adoption of the principles and methods by which it has been attained, in those other localities which up to the present have not yet fully adopted them.

There may be, and doubtless are, some makers who are still of opinion that with their particular materials the principles and methods of so-called modern blast-furnace practice are not applicable. It is with the hope of convincing them, and of strengthening the growing belief of others, that the author has undertaken this paper, for it is his firm conviction that those principles and methods are adaptable to any iron-bearing materials which are workable in a blast furnace, subject, of course, to suitable fuel and flux being obtainable within even a wide degree of quality, and subject, likewise, to a minimum degree of variation in that quality for any individual operation. He feels convinced that their adoption will lead to so great an advantage as to constitute almost a revolution in the pig-iron industry in those localities where they have not hitherto been applied.

The four prime factors above referred to are: (I) Preparation of Materials; (II) Furnace Design; (III) Auxiliary Equipment; (IV) Method of Operation.

### I. PREPARATION OF MATERIALS.

That the mechanical and physical conditions of the materials charged into a blast furnace have a most important bearing upon its successful and satisfactory operation, affecting both its operative conditions and the economy of the results obtained therefrom, is a fact which no blast-furnace operator is likely to dispute, but while it is true of any blast-furnace it is particularly true in its bearing upon the operation of the modern blast furnace. One of the essential conditions of satisfactory operation is that there shall be as nearly as possible uniformity of chemical reactions, and of physical movement of the materials throughout the whole cross-section in every zone of the furnace. Two elements are required to obtain this in theoretic perfection, namely, perfect uniformity in the size and density of the materials charged, and a sufficient blast volume to produce the condition of a plenum throughout the whole furnace interior. While it is, of course, impracticable to obtain for blast-furnace use materials of perfectly uniform size and density in each of the three classes of materials used in pig-iron smelting—fuel, flux and ore—it is practicable to approximate to a degree to that condition by the use of proper means for their preparation. It is obvious that the feature which most directly bears upon the essential condition above mentioned is that of distribution, and in order to obtain as nearly as practicable uniformity of distribution such preparation as will give as nearly as practicable uniformity of size must be resorted to. For reasons which will be referred to later, uniformity of size only is not, however, sufficient, for example, uniformly large size, while giving uniformity of distribution, would be detrimental to economical operation. The preparation of materials must be in the direction of uniformly small size.

*Fuel (Coke).*—While this principle is much more important in its application to the ore and flux than to the fuel, it also applies, to a degree, to the latter. As rapidity of action is largely dependent upon rapidity of combustion of the fuel, it is desirable that the fuel should not be charged in lumps of excessive size, and preferably should not exceed 4 in. to 6 in. This is, of course, assuming that the coke is of proper physical condition. It may be said here that the physical quality and chemical purity of coke for blast furnace use are of the greatest importance. It should be strong but of not great density, and as low as possible in ash and sulphur. There is nothing which more greatly interferes with the regular and economical operation of a blast furnace than soft, friable, or high ash coke, as everyone connected with the industry has experienced during late years under the conditions existing during, and for some time after, the late war. The disadvantage of high sulphur in the coke need not be emphasised.

The coke as charged into the furnace should be thoroughly screened to free it from smalls, commonly known as breeze, and should be of sufficient strength to prevent the excessive formation of smalls in the furnace through the crushing effect of the burden. The strength should not, however, be of the kind which is

produced by great density, which destroys the cellular structure. A dense coke burns slowly, and is, therefore, inimical to rapid combustion, which is necessary for fast driving, whereas cellular structure permits the heat and the agents of combustion to penetrate readily to the interior of the lumps, thus facilitating combustion. On the other hand a very open cellular structure produced at the expense of strength is equally to be avoided as tending to produce smalls through its lack of resistance to crushing by the weight it has to bear, and abrasion by its movement in the furnace. Such a fuel is also subject to excessive waste in the upper regions of the furnace before it reaches the zone of its usefulness, owing to the greatly increased reaction upon it of the $CO_2$ in the gases—$CO_2 + C = 2CO$. It is, therefore, of the greatest importance, in modern blast-furnace practice, that coke-makers should give the greatest possible attention to the production of a coke combining these two essential features—strength and porosity. There are a number of factors entering into this problem of blast-furnace coke making, by the careful study of which the makers may arrive at the production of coke having the desired physical properties described above. Some of these are the coal mixture, the mechanical condition of the coal as charged and its compactness in the oven, the oven temperature, the rate of carbonisation, and uniformity of coking action throughout the coking chamber. It would seem hardly necessary to mention the great importance of chemical purity in the coke, as naturally the higher its carbon content the greater its efficiency. It is surprising, however, how much coke is produced with high ash and sulphur content for blast-furnace use; in many cases, undoubtedly, the result of insufficient or inefficient washing of the coal, or insufficient attention to the selection of the coal for the production of blast-furnace coke. Care in selection and efficient washing of coal for coke production are, therefore, of very great importance in their bearing upon economical blast-furnace operations, and every possible effort should be made by blast-furnace owners to induce coke-makers to meet their requirements as to mechanical, physical, and chemical quality. It is the carbon which does the work in the furnace, and every decrease in the percentage of ash increases the available carbon and tends in other ways towards a higher degree of efficiency. In addition to the higher fuel value of low ash coke, it is lighter in weight, requires less limestone for fluxing the ash, and a lower amount of the fuel charged is required for forming and melting the slag produced from the coke ash. It is estimated that the formation and melting of blast-furnace slag requires approximately 25 per cent. of its weight in fuel, therefore, for every hundredweight of slag produced from coke ash ¼ cwt. of fuel is lost so far as the smelting of iron ore—the primary object of the blast-furnace process—is concerned.

*Iron Ore.*—From the standpoint of preparation, the iron ore is the most important of all the materials charged into the blast furnace, owing to the extremes in mechanical condition, from fines to large lumps, in which most iron ores are received from the mines, and the great variety of physical characteristics in different ores. The operation of the blast furnace is much more usually affected, for good or ill, by the mechanical condition of the iron ore than that of either fuel or flux. It is, therefore, of prime importance that this condition should receive very careful attention, and whatever steps are necessary should be taken, in the way of preparation, to convert it to that condition—or as near to it as is practicable—as will insure the most beneficial effect upon the furnace operation. There are two principal features directly affected by the condition of the iron ore, both bearing upon the rate of production and upon economy. These are reducibility and distribution. The degree of reducibility of an iron ore depends primarily upon its density, a characteristic which in itself is not readily altered, except with dense ores containing high percentages of protoxide of iron (magnetite), the reducibility of which may be increased by subjecting them to a roasting process in an oxidising atmosphere, thus converting the protoxide to peroxide of iron.

*Rough Ores.*—The rate of reduction in the furnace may, however, be materially increased for any particular ore containing lumps, whatever its degree of density, by increasing the surface area exposed to the action of the reducing agents. The obvious method of attaining this increase in surface area is by breaking the lumps into a number of smaller pieces. The extent to which this operation may be carried is, of course, limited by the cost of breaking the ore (a commercial consideration), and the tendency of any particular ore to produce an excessive proportion of fines in the breaking. The latter tendency, however, really does not exist to any considerable extent in ores whose condition allows of their being broken at all, for whatever smalls may be produced in the breaking are usually of sufficient size not to be classed as fines, and may, therefore, be safely charged into the furnace with the larger products of the breaking operation.

The increase in the rate of reduction obtained by thus increasing the surface area exposed to the agents of reduction in the furnace, has, in addition to the higher possible rate of production, a very important effect upon economy of production. There are two principal reducing agents in the blast-furnace process, carbonic oxide and solid carbon, and it is generally accepted that reduction of iron oxide by carbonic oxide, in the upper zones, is a much more economical reaction than the reduction of iron oxide by solid carbon in the lower zones. It is, therefore, highly desirable that the whole or the greatest possible portion of the iron oxide should be reduced by carbonic oxide gas, and that this reduction should be completed before any lumps of iron oxide have reached the zone where conditions permit, in excess, the uneconomical reaction between them and solid carbon. It is obvious that the surest way of attaining this is so to increase the possible rate of reduction of the ore by increasing its surface area, as described above, that the maximum reduction may be effected by the carbonic oxide gas in the upper zones of the furnace. If this precaution of increasing the surface area by breaking the lumps of ore before charging into the furnace is neglected, the larger unbroken lumps will escape thorough reduction by carbonic oxide gas with consequent waste of fuel, particularly if any attempt be made to increase materially the rate of production by rapid driving. To obtain a high rate of production, with economy and quality, it is therefore necessary to prepare the ores in the manner described.

The degree to which it is commercially practicable to crush an ore depends upon its density. Experience has indicated that all ores should be crushed to sizes not exceeding such as will pass through a 3-in. or 4-in. ring, although ores of great density may be advantageously crushed to even smaller sizes. The standard of 3 in. or 4 in., while seemingly rather small for ores of a high degree of reducibility—the so-called "soft" ores—is not determined wholly from the standpoint of degree of reducibility, but also by its bearing upon distribution.

The question of the distribution of ore in a blast-furnace is of the highest importance in its bearing upon regularity of operation, this in turn affecting most vitally the economy, quality, and output. This question has been referred to above in a general way in connection with uniformity of action in the furnace, but important as that is as regards all the materials, solid and gaseous, entering into the blast-furnace operation, the distribution of the ore is the most important consideration in regard to the solid materials. In the consideration of this question it is necessary to keep in mind the great essential—equality of action throughout the whole of every cross section of the furnace interior. Except for the fact that the operations are taking place in a vertical shaft of circular cross section, this result would be obtained, theoretically, only with materials of exact uniformity in size and density, but the fact just mentioned introduces a feature which interferes with this theoretical requirement. It is a well-known fact that the gases have a natural tendency to ascend next to the walls and would do so to the neglect of the interior if the furnace were filled with materials of exact uniformity in size and density. It is necessary, therefore, in order to secure approximate equality of action, to have a somewhat greater resistance to the passage of the gases in the materials nearest the walls than in the interior. It is to this condition that the ordinary bell and hopper charging apparatus owes its satisfactory use, discharging the materials as it does in such a way that a greater proportion of the smaller particles remains next to the walls, thus providing the somewhat greater resistance to the ascending gases required there. In order that this distribution by bell and hopper charging may give the desired result the relation of the diameter of the bell to the diameter of the furnace throat at the stock line is of material importance, as likewise that the falling materials shall first strike the materials in the furnace, when nearly full, at about 18 in. from the walls. The former relation requires usually a bell diameter 4 ft. to 5 ft. less than the throat diameter at the stock line. The bell angle is usually 40 deg. to 45 deg., and in some cases 50 deg.

This method of charging results in the surface of the material in the furnace assuming the shape of an inverted cone with its base about 18 in. from the walls, from which point it slopes away slightly to the surface of the walls. The smallest particles lie on the base of the cone, and between it and the walls, together with a portion of the smaller lumps and rubble. The inner slope from the base to the apex of the cone consists of pieces of gradually increasing size with practically only the largest lumps at and near the apex. This description does not, of course, apply to an ore mixture consisting of all fines, or of lumps, of uniform size, conditions which very seldom exist in blast-furnace practice, but it does apply to the usual run of ores which consist of a mixture of fines, rubble, and lumps.

It is obvious that the greater the difference between the largest and the smallest pieces, or, in other words, the larger the lumps the greater the sorting action above described, and conversely, the smaller the maximum size of the lumps the less the degree of segregation. It is, therefore, further obvious that to avoid excessive segregation, the preparation of the ore by crushing the lumps to smaller, say rubble, size is necessary. The crushing of the lumps prevents excessive segregation in two ways; first being smaller, they have less tendency to roll down the sides of the inverted cone to the apex, and, secondly, the broken pieces have usually sharp and jagged edges, and have, therefore, a greater tendency to lodge nearer where they fall; the movement of the materials to the centre is more likely to be *en masse*, carrying a certain amount of smalls with it. It is thus that preparation by crushing materially improves distribution by preventing excessive segregation, which is a condition directly inimical to the application of modern blast furnace practice.

In the distribution existing when the usual run of ores and limestone are charged "as received," there is, as described above, a core, or column in the centre of the furnace consisting almost entirely of the largest lumps, the area of the cross section of this core varying with the size and proportion of lumps to rubble and fines. Between this core and the walls there is an annular ring consisting of a mixture of rubble and smalls, in which the proportion of rubble to smalls gradually decreases until, next to the walls, there are practically only smalls and fines. As previously pointed out, an essential to regular and economical descent of the materials is perfect uniformity of action of the ascending gases upon the whole of every cross-section of the material in the furnace, and while this is an ideal condition which may be impossible of full attainment in actual practice, the nearest possible approach to it is of the greatest importance. There can be very little approach to such a condition if the ascending gases are forced, under pressure, through a mass of materials distributed as just described. Very little, if any, of the gases will find contact with the closely packed fine materials close to the walls, and the greater proportion will pass up through the more open structure in the centre, the core of large lumps, and a proportion only through the ring of rubble and smalls. The result of this unequal distribution of the ascending gases is the faster descent of the largest lumps in the centre, and a gradually slower descent of the outlying materials. Such a descending movement of the materials of the various sizes is exactly contrary to what is most desirable. Those which descend most rapidly, owing to their slower rate of reducibility should descend most slowly, and those which descend most slowly, owing to their high rate of reducibility should descend most rapidly. Maximum economy and output are impossible under such conditions, for apart from the question of irregularity of movement which almost always results from them (see below), it is necessary to provide an excess of fuel to insure the complete reduction of the more rapidly descending lumps before they enter the melting zone (see above, under Reducibility), and the rate of driving is limited by their slower rate of reducibility. Any attempt at really fast driving under these conditions so reduces the ratio of ore to fuel which can be carried that not only is the output not increased, but the fuel consumption is very greatly increased, with the added danger of the production of low grade iron through unreduced ore entering the furnace hearth from over driving, or irregular descent of the materials.

Under the conditions existing in a furnace charged in the manner under consideration, there is always a strong tendency towards irregularity of movement, or none at all, in the material nearest the walls, with a gradual building up on the walls. This building up continues until portions either become permanently stationary, forming scaffolds, or masses break away and are precipitated towards the centre and into the actively descending materials and rapidly ascending gases, constituting the well-known slip. This procedure is more or less frequent and more or less severe, from the small slip, causing temporary production of off grade iron, to the heavy slip or explosion, which either blows off the furnace top, or fills the tuyers with slag, chills the hearth, "gobbs up" the furnace and puts it out of commission for days, an evil too well known among those who may be interested in this paper to require any emphasis; but to whatever degree it occurs it very seriously interferes with the regularity which is essential to the best results. The disadvantages from the accumulated effects of these conditions are only avoided, and even then not always satisfactorily, by periodical partial clearance of the furnace walls by the use, temporarily, of considerably reduced burdens, or, which is the same thing, by charging extra fuel, at the expense of both economy and output. These evils can only be avoided by the proper preparation of lumpy ores by crushing.

*Fine Ores.*—The disturbing effects upon blast-furnace operations of the use of any considerable proportion of very fine ores—exaggerating the conditions described under Distribution—are too well known to require special emphasis. Although in modern practice furnace design and method of operation have considerably reduced these effects, such ores are still sufficiently objectionable in this respect to make advisable some treatment to change their character as fines. In this case the process of preparation is the reverse of that for lumpy ores, that is, instead of reducing, it is desirable to increase their size, in order to remove their clogging effect in the furnace, and to prevent their being carried out in excessive quantities, by the escaping gases, into the gas flues. Various processes have been introduced for this purpose, such as briquetting, nodulising, and sintering, each of which yields a satisfactory product for use in the blast-furnace. Sintering is the more recent process, and has grown very rapidly in favour, owing to its lower production costs, and the large range of materials which may be treated by it, including blast-furnace flue-dust, the recovery of which alone in some cases warrants the installation of the process, particularly as, in addition to the iron ore recovered, the dust usually carries such an excess of fuel over what is required for its own treatment that a considerable proportion of other fine ore, without fuel, may be mixed and sintered with it. By these processes, and particularly sintering, many ores which, in their natural state, are unsuitable for use in the blast furnace, either owing to their mechanical condition, or high sulphur content, or both, may be rendered suitable.

*The Flux* (*Limestone or Dolomite*).—Of the solid materials, the flux, being easily acted upon by the heat and chemical reactions, and usually forming a small proportion of the mixture, is of less importance in connection with the question of preparation of materials. It is of sufficient importance, however, to receive consideration, as its mechanical condition has a definite bearing both upon distribution and rapidity of action in their bearing on economy. Although the effect is less in degree, it is the same in principle as in the case of the ore, and for similar reasons the flux should be broken to as nearly as practicable uniform size. In practice it has been found sufficient to break it to sizes not exceeding 4 in. or 6 in., or such as would pass through a 4-in. or 6-in. ring, although there is no disadvantage in breaking it to even smaller sizes. The author has had personal experience with large blast-furnaces using oyster shells alone as flux over a considerable period with perfectly satisfactory results, except that there was added to the waste gases a further objectionable feature to their usual asphyxiating qualities, their bad odour.

*Blast.*—The only remaining "raw material" essentially used in blast-furnace operation is the air which supplies the oxygen necessary for the combustion of the fuel. There is little to be said with regard to the blast under the heading of Preparation of Materials, that is, in its bearing upon modern blast-furnace practice as distinguished from practice which is not "modern," except that the usual custom in the latter is to take the air as we find it, although not always in all its purity. Too little attention is usually paid to this point. Natural air in its purest state has its detrimental constituents, but as a rule little attempt is made to draw the supply for the blowing-engines even as pure as possible. The proximity of boilers and free exhaust auxiliary machinery, and various sources of evaporation, too often charge the air near blast-engine houses with quantities of moisture much in excess of that in natural air "in its purest state." In modern practice practically all exhaust steam is condensed, and a large proportion of the auxiliary machinery is electrically driven. There is, therefore, little, if any, opportunity for extraneous moisture to enter the blast engines with natural air. This is a feature of considerable importance, and has an appreciable bearing upon the economy of modern practice.

Although in view of its lack of more general adoption it has no direct bearing upon the subject of this paper, there is a treatment to which natural air may be subjected for its improvement for blast-furnace purposes, which comes logically under the heading of Preparation of Materials. As a strong advocate of this treatment the author hopes that a discussion of it at this point will not be considered out of place. This is the question of dry blast, or, to be more exact, the treatment of natural air for reducing its hygroscopic moisture to a uniform and low content—a treatment first introduced and practically demonstrated by James Gayley in 1904. There has been a great deal of discussion, and even contention (mainly theoretical), as to the merits of this process. At the time of its introduction a great stir was caused in iron-producing centres, and during the following years a considerable number of plants were installed for its use in the United States more particularly, and in Europe. Some of these installations are still used continuously, and some are used intermittently in the United States, that is, they are used in the summer months when the moisture content of the air is high, and discontinued in the winter months when the moisture is naturally low. In other cases their use has been entirely discontinued.

There is, however, practically unanimous agreement amongst those who have used "dry blast" that its use does improve blast-furnace results, although opinions differ as to the degree of the economy. The author has had an opportunity during the past eighteen months of discussing this matter with representative American blast-furnace operators, particularly as to the reasons why the process has not been more generally adopted and its use continued more generally where plants have been installed. The explanation given is that the benefits obtainable from "dry blast" have been superseded by the great advance in blast-furnace results brought about in recent years by improvements in furnace design, and the altered practice following those improvements. In other words, it has been possible to obtain, in other ways, advantages equal to those derivable from "dry blast" under the older practice. It may be a very bold thing for the author to say in the face of these opinions, but he believes that attitude to be a mistaken one, and that if every advantage which can be derived from "dry blast" is provided for, further improved results are obtainable in addition to those already obtained by the means above referred to.

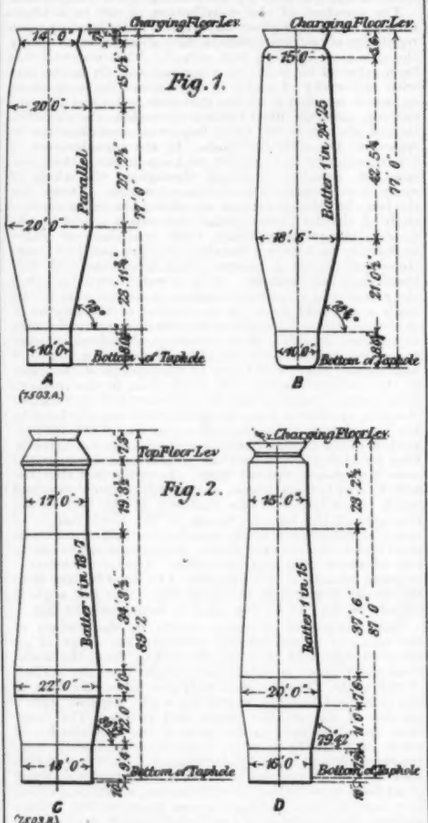
The author has had considerable experience with "dry blast," having used it continuously on two large furnaces during the past thirteen years with such satisfactory results that he would have considered its abandonment a very serious step in the wrong direction. It is not his intention to enter here into a discussion upon the advantages of "dry blast" in detail or in general, but there is one very important feature in connection with its use which seems to have been missed by those who have used and abandoned it, either partially or wholly, a feature which, in all probability, explains the attitude adopted towards it in the United States in conjunction with later American practice, and possibly elsewhere. This is the important factor of blast temperature. It is the author's experience and he believes it is also general experience (although there may be isolated cases to the contrary), that with natural air there is an upper limit to the temperature of the blast which can be used with satisfactory and smooth working for any particular furnace. Any considerable increase beyond this limit causes "stickiness," "hanging," and irregular movement of the materials in the furnace. In his discussions with American blast furnacemen he was told that this was the case even with furnaces of the latest design, and a particular case was cited at one of the most modern plants in America, where very high temperatures of blast were tried with results as above mentioned. The blast temperatures generally used range from 1,150 deg. to 1,250 deg. F., while with clean gas and modern stove design (and sufficient stove capacity), temperatures as high as 1,500 deg. to 1,600 deg. F. are obtainable.

The economical advantage which could be derived were it possible to make satisfactory use of this additional heat in the blast, need hardly be emphasised, and any practicable means which would render this possible would confer a very important boon upon the iron-producing industry. The author's experience is that such a means is available in "dry blast," and that it is this further advantage of dry blast added to those which are already conceded to it, which would, if taken advantage of, settle the doubts of those who are still undecided, and convert those who have already condemned it. It may be said that he was in a fortunate position to have available such high temperatures (he has used temperatures as high as 1,600 deg. F., normally from 1,450 deg. to 1,550 deg. F., temperatures under 1,400 deg. F. being considered too low), but what was available to him is obtainable by others, and he would emphasise the fact that without dry blast, although available, he could not have used them.

## II.—Furnace Design.

In the sense in which this heading bears upon the purpose of this paper it refers not to the structural detail of the furnace as a whole, but to that portion only in which the metallurgical operations take place; that is, the furnace proper, the interior space, the design of which is technically known as the "lines of the furnace."

The terms usually used to describe the lines of a blast-furnace divide it into a number of sections, namely, the hearth or crucible, which is cylindrical; the bosh, an inverted truncated cone; the shaft, an upright truncated cone; and the throat—in modern furnaces usually




cylindrical—extending from the top of the shaft to the top of the furnace. The principal dimensions of these sections consist of heights, diameters, the acute angle of the bosh wall to the horizontal, and the batter of the shaft wall to the vertical. Each of these dimensions has a very important bearing upon all the others, and their relation to each other is of the first importance as a factor in modern blast-furnace practice; for although they may vary somewhat in their relation, the variations are limited to conform to certain principles, the height of the furnace and hearth diameter being the dimensions which control all the others.

Under this heading—Furnace Design—the author proposes to outline and discuss these principles, and to enunciate as a general law the principle that the output capacity of a blast-furnace (with any particular set of raw materials) is in proportion to the effective bosh area. The point of this law is the word effective, for as will be later shown the maximum effective bosh area is dependent upon the various factors which constitute the principles of modern blast-furnace practice.

Modern development in blast-furnace design has established the following essentials. A shaft batter of 1 in 13·5 to 15, the low bosh, the large hearth diameter, and the steep bosh angle—all of which are, of course, comparative terms in their relation to similar features in the older designs.

The diagram above shows two furnaces, A and B of pre-modern lines (extreme cases have been chosen to emphasise the principles under discussion), and two furnaces, C and D of modern lines (the tendency is further to increase the hearth diameter, and a furnace is now in successful operation with a hearth diameter of 20 ft. 9 in., but in this direction it is sufficient for the present purpose to avoid the extremes).

*Throat and Stack.*—The upper section of the furnace or throat is, as above mentioned, usually cylindrical in shape and extends to from 20 ft. to 25 ft. below the furnace top or 12 ft. to 17 ft. below the stock line, the highest point to which the furnace may be filled. The adoption of the cylindrical throat is primarily in order to obtain the desired batter to the shaft walls, although it also has a bearing upon regularity of distribution by presenting to the charged materials an area of the same dimensions for the varying positions of the materials in the throat due to their constant movement. The latter point, however, is not of great importance in the modern furnace plant as the charging appliances are usually, or should be, of ample capacity to keep the furnace fully charged at the highest rate of driving.

Within the distance to which the cylindrical throat extends the condition of the materials is such that there is no tendency for them to adhere to the walls or to hang through jamming or arching, as they are in a "dry" condition, both as to moisture and pastiness, and their expansion through increase in temperature is not yet sufficient to require increased space for their accommodation so as to avoid the danger of restricting free movement. Below this point, however, temperature increase becomes much more rapid and reactions much more intense. In this alteration in condition and temperature, which is progressive as the materials descend, more space accommodation is required for free movement, more particularly because to expansion is added the semi-pasty and pasty condition, and the increased density of the mass through the increasing load bearing down upon it from the increasing weight of superimposed materials. It is also probable that the question of carbon deposition enters into the necessity for greater space accommodation as the materials descend into the hotter and more active regions of the furnace. Hence the necessity for the expanding batter to the shaft walls. It would also seem obvious that the more rapid the descent of the materials into and through these zones (faster driving), the greater must be the increase in space accommodation. In the older furnace designs, with slower driving, shaft batters as low as 1 in 26, and possibly less, were in use. In modern practice it has been found necessary to increase this batter to 1 in 14, or thereabouts. The principles involved in this feature of modern blast-furnace design are of the greatest importance, and probably explain, in part at least, why many furnace managers have failed in their attempts to apply fast driving to furnaces with lower shaft batter.

To revert for a moment to throat diameter, there are in this feature several opposing conditions to consider. The lower the velocity of the gases as they leave the furnace top, the lower the loss from flue dust carried over with them. The largest possible throat diameter is, therefore, desirable for this reason. On the other hand, the extent to which this feature may be provided for is limited by the question of distribution, both of the materials charged into the top and the ascending gases, as regards the most uniform action of the latter over the whole cross-section of the former. The throat diameter is also limited by the required shaft batter, and the bosh diameter and height. Sacrifices must, therefore, be made in one direction or the other, and as the question of losses by flue dust is largely affected by regularity of stock movement, features tending to the latter should have first consideration. Throat diameters are, therefore, restricted in modern furnaces of 85 ft. to 95 ft. in height to from 15 ft. to 17 ft., the controlling factors being the other dimensions such as hearth diameter, bosh diameter, and height.

*The Low Bosh.*—The low bosh was the direct outcome of attempts to increase blast-furnace outputs by increasing the volume of blast blown per minute. These attempts with the old high bosh furnaces resulted in seriously increased furnace irregularities, the reason for which became apparent from the study of the altered conditions brought about in the furnace through the more rapid driving, and the troubles experienced. With the much more rapidly descending materials it was found necessary that the contracting part of the furnace, that is, the top of the bosh, should begin below the upper limit of the zone of fusion in order to prevent the pasty materials just above the zone of fusion entering the contracting area, where they would be subjected to a squeezing action as a result of the resistance of the bosh walls, and the weight of the superimposed materials, with the consequent tendency to pack and cause hanging and the formation of scaffolds on the upper bosh walls.

The continued lowering of the top of the bosh followed therefore the continued attempts at faster rates of driving for larger outputs, until in modern practice a bosh height for 85 ft. to 95 ft. furnaces, of 10 ft. to 12 ft. above the top of the crucible, has been adopted as compared with as much as 30 ft. in the old design. Whilst it is true that no one would build a furnace with a 30 ft. high bosh to-day, there are furnaces in operation of recent design with boshes 16 ft. to 18 ft. or even higher. Any attempt to drive such furnaces rapidly is sure to result in increased irregularity and consequent failure. The basis of this principle—the low bosh—is, therefore, that the furnace must be so designed, as regards bosh height, that the expanding portion of the furnace, that is, the shaft, shall continue to a point slightly below the beginning of the melting zone, so that no pasty materials shall enter the contracting portion at the top of the bosh. In actual practice many, in fact most, modern furnaces are designed with a cylindrical section from 5 ft. to 8 ft. in height between the lower limit of the expanding shaft and the upper limit of the contracting bosh. This section has no justification from the standpoint of any principles involved in its adoption, except that it fills up with brickwork the angular space at the junction of the bosh and shaft, which to a degree may be considered "dead space," and renders less abrupt the

transition from the expanding shaft to the contracting bosh, but is rather the result of necessity in order to obtain the desired relation between other features such as shaft batter, throat diameter, and bosh diameter and height.

The bosh diameters, for what may be called full-sized blast-furnaces, that is from 85 ft. to 95 ft. high, are usually from 20 ft. to 23 ft. with a bosh angle of about 80 deg., while in pre-modern designs this angle was anything from 68 deg. or less to 74 deg. The latter feature is the result of the progressive increase in hearth diameters, and, as the author will endeavour to show further on, these two features, the steep bosh angle and the large hearth, are concomitant, and their evolution the result of efforts to overcome irregularities through the failure of earlier designs (with the flatter bosh and smaller hearth diameter) to bring into operation the maximum effective bosh area, which is, of course, the full bosh area.

*The Hearth or Crucible.*—In the modern full-sized furnaces hearth diameters are normally from 16 ft. to 18 ft., although, as has already been mentioned, in one instance this dimension has reached 20 ft. 9 in. At present, however, the latter may be taken as an extreme, and it remains to be seen whether hearths of this size are likely to be generally adopted. In the process of evolutionary experiment it is often necessary to over-reach the maximum in order to ascertain what it really is. The hearth diameter of a blast-furnace would seem, at first sight, to be the determining factor for its output capacity, and, in the sense that it is the starting point in the design, and, with the bosh angle and bosh height now generally adopted in modern design, practically determines the bosh diameter, it is so; but in the sense that the hearth diameter, together with the low bosh and steep bosh angle, are merely means for making effective the maximum bosh area, it is not really the determining factor, which is the bosh diameter. The hearth, or more properly the crucible, is the receptacle for receiving and storing from cast to cast the molten materials, while the bosh area is the active area in which the molten materials are produced as such, and the proportion of that area which is in active operation is the determining factor as to the quantity of molten materials available for collection in the crucible.

In all previous references to the various dimensions of the modern blast-furnace, and the principles which have led to their adoption, it is, of course, assumed that in the operation of the furnace the volume of blast is in keeping with the size of the furnace, and is such as will provide the operating conditions upon which those principles are based. In modern practice the volume of blast is normally from 40,000 cub. ft. to 50,000 cub. ft. of free air per minute delivered from engines capable of delivering these volumes against pressures, or rather resistances, up to 25 lb. or 30 lb. per square inch, to provide ample reserve power for conditions causing abnormally high pressures. Normal working pressures are usually between 15 lb. and 20 lb.

*Effective Bosh Area.*—This term, used several times in the foregoing is, the author believes, a new one in blast-furnace nomenclature, but it is one which has a meaning of the first importance in blast-furnace operations.

A general law enunciated in the foregoing was to the effect that "the output capacity of a blast-furnace, with any particular set of raw materials, is in proportion to its effective bosh area." Before discussing this proposition it is necessary to define: (1) What is the "effective bosh area"?; and to consider (2) what are the factors which control or determine the effective bosh area?; (3) what bearing have these factors (through their determination of the effective bosh area) upon the output capacity of the furnace?

(1) The effective bosh area is that portion of the full horizontal bosh area at its maximum diameter which is in normal activity under the conditions of operation of the furnace.

(2) The factors which control or determine the effective bosh area are those which are under discussion in this paper, namely, the condition of the materials charged, the furnace lines, and the volume of blast blown per minute in relation to the size of the furnace.

(3) The bearing these factors have upon the output capacity of the furnace is that they determine the area of activity in the melting zone.

The whole trend of evolution in blast-furnace practice has been in attempts to devise means of increasing output capacity, consistent, of course, with quality and economy, and the degree to which these attempts have been successful in modern practice has been due to the influence the factors in that practice, as described in this paper, have had in increasing the ratio of effective bosh area to the maximum or designed bosh area of the furnace, or to put it in simple terms, to keeping the walls clean. It is, therefore, conversely true that the effective bosh area of blast-furnaces, where the factors upon which modern practice is based have not been adopted, or which are not operated in conformity with its principles, is less than the maximum or designed bosh area.

As has been described under (I) Preparation of Materials, the direct tendency of lack of such preparation is towards restriction of active area in the furnace. Under furnace design the tendency of the high bosh and the low stack batter is shown to be towards restriction of active area in the furnace. Equally the tendency of the small hearth and flat bosh angle is towards restriction of effective bosh area, owing to the removal of the area at, and adjacent to, the top of the bosh near the walls too far horizontally from the upward moving gases, with the consequent tendency for accumulation of torpid or stationary materials in that area. As previously described, for a furnace of given size, insufficient blast volume to ensure equal activity throughout the whole cross-section at every altitude tends to the production of inactive areas owing to the impossibility of providing perfect uniformity of materials. The greater this lack of uniformity, the greater this tendency. The under blowing of a blast-furnace is one of the most fruitful causes of reduction of effective bosh area, with outputs far below maximum output capacity.

The tendency of a blast-furnace is to adjust its active areas to the volume of blast supplied to it. This tendency is in strong evidence where furnaces which have been blown for a considerable period with comparatively small blast volume, have been suddenly and too quickly supplied with a considerably increased volume. Operators who have made this experiment will doubtless recall the difficulties they have experienced through irregular working. The author knows of cases where, although the furnace size was quite suitable to the increased blast volume, the attempt has been abandoned through the conclusion that conditions were not suitable to faster driving, whereas a little persistence would probably have overcome the difficulties met with by the walls gradually clearing, and the furnace thus adjusting itself to the larger blast volume. It is, of course, true that many blast-furnaces in operation to-day are not adaptable to modern practice in its fullest sense. One or more of the necessary factors are lacking, and, as the author has attempted to show, each of these factor is so dependent upon the others that they must all be present for its full application. Among them, however, there is one, preparation of materials, which, if adopted alone, would provide conditions which would render possible the partial application of others with decided improvement in results, and tend to remove many of the difficulties now experienced.

### III. Auxiliary Equipment.

Under this heading it is not intended to enter into, nor does the purpose of this paper call for, a detailed discussion of the many units comprising the auxiliary equipment of a modern blast-furnace. There are, of course, certain units which are essential to the operation of any blast-furnace. Where, for the purpose of emphasising the requirements of modern blast-furnace practice, it is necessary to discuss the modern features of these units they will be specifically referred to. There are also certain units which, while not essential to blast-furnace operation in general, are essentials, from the standpoint of economical operation, to modern practice. These will be discussed in more detail, but only so far as the principles involved in their adoption are concerned.

The auxiliary equipment, or plant required for the operation of a blast-furnace, may be divided into four sections: (1) The power plant; (2) the blast heating plant; (3) the raw material supply plant; (4) the output disposal plant.

Equipment falling under one or other of these sections is essential to the operation of every blast-furnace (excepting, of course, a cold-blast furnace which need not be considered here). In modern practice, however, there are certain features in the details of the plant required, bearing upon the method and economy of operation, which are essential to the full adoption of that practice.

1. The term "power plant," which is used here in its most comprehensive sense, covers all apparatus for producing and utilising the power required for sustaining the blast-furnace operations. The principal among these are the boiler plant, the blowing-engine plant, the electric generating plant, the water-pumping plant, and, in some cases, the hydraulic power and compressed air plant (and it might be added the dry-blast plant). With regard to most of these items, it need only be said that they should be of the most modern, simple, and economical type, with ample reserve of power and capacity, in order to minimise those costly furnace stoppages which are otherwise likely to occur through mechanical failures, or interference with normal operation through lack of efficiency. In other respects they do not, with the exception of the blowing-engines, bear directly upon the principles of modern blast-furnace practice. In regard to blowing-engine capacity, and—in one particular feature—to turbo blowers, there is a point which it is important to emphasise. As previously stated, the volume of air required for the normal operation of a full-sized modern blast-furnace is from 40,000 cub. ft. to 50,000 cub. ft. of air per minute. It is important that this air should be delivered in as continuous a flow—that is, as free from pulsations—as possible. With reciprocating engines, the speed and number of blowing cylinders should be as great as possible consistent with engine safety and efficiency, and the range of volume delivered, with a fair degree of economy, as wide as possible. The engines should also be designed to deliver their maximum volume against pressures up to 25 lb. to 30 lb. per square inch with steam pressure or gas of quality at least 20 per cent. below the normal, in order to provide for those abnormal conditions to which every blast-furnace is liable. As regularity in air volume delivery is an essential of modern blast-furnace practice, every blowing-engine should be equipped with an efficient governing device.

As above mentioned, the centrifugal or turbo blower is widely used, and is rapidly growing in favour for blast-furnace work. Well-designed blowers of this type have a number of advantages over the reciprocating type. They are simpler in design. Per unit of capacity they are lighter in weight, require less floor space, less massive foundations, and are lower in first cost. They have fewer moving parts, have no losses through reversal of motion, are lower in cost of maintenance and repairs, require less attention in operation, and are much easier and less costly to lubricate. They have the advantage of giving a continuous flow of blast delivery, being entirely free from the pulsations in delivery, within their rated capacity, characteristic of the reciprocating type. There is, however, one feature in the turbo blower, as compared with the reciprocating blower, which must be specially provided for to ensure its suitability for modern blast-furnace practice. As above stated, regularity or constancy of the volume of free air per minute, required by the furnace operator for the time being, is an essential of that practice. This volume must not materially vary or be affected by the more or less varying resistance, commonly called pressure, on the delivery side of the blower, due to the varying furnace conditions. In reciprocating blowers this requirement offers no difficulty, as regularity of the volume delivered is assured by regularity in engine revolutions, whatever the resistance, within the limits of the capacity of the blower. In the turbo blower, however, the volume delivered varies both with the engine revolutions and the resistance on the delivery side. The turbo blower, therefore, requires for its satisfactory application to modern blast-furnace practice a special type of governing or controlling device in order to assure the delivery of a constant volume of blast per minute against the varying resistance offered by the varying furnace conditions—that is, a volume controller. For many years this feature in the turbo blower was a serious drawback, notwithstanding its many other advantages, to its adoption for blast-furnaces. Its general adoption and growing use in recent years is directly due to this difficulty having been successfully solved through the design and application of an efficient volume regulator.

2. The blast heating plant consists essentially of the hot-blast stoves and their connections, for receiving cold-blast from the blowers and waste gases from the furnace, and for delivering hot-blast to the furnace and consumed gases to the atmosphere. Under this heading should be included another installation which, while not essential to blast-furnace operation in general, is from the standpoint of economy an essential part of modern blast-furnace equipment. This is the gas-cleaning plant, or rather, a rough gas-cleaning plant as distinct from the plant required for the high degree of gas-cleaning necessary for use in gas-engines. The advantages and economies obtainable by the use of clean gas as compared with uncleaned gas are many, and of very considerable importance, and far outweigh the cost of installation, operation, and upkeep, &c.

Though this question has already been fully discussed by various writers, a number of these advantages, some of which also apply to the boiler plant, are enumerated as follows: (1) A much higher thermal efficiency of the gas is obtained through more perfect combustion, by better control of air and gas mixture, and the elimination of fume and other heat absorbing solid matter, with the consequent increase in the heat units available for absorption by the stove checker bricks and boiler flues. (2) The saving of the labour constantly required for cleaning stoves and boiler flues. (3) The saving of labour and materials required for repairs to stoves necessitated by the fluxing effect of the solid matter in uncleaned gas on the brickwork. (4) The much longer life of stove linings through the absence of these destructive effects of uncleaned gas. (5) The much greater time service per stove—and per boiler—through the elimination of lost time for cleaning and repairs. (6) The much greater possible heating surface per unit of stove volume through the use of smaller checker openings, and the higher efficiency thus obtainable. (7) The greater regularity in blast temperatures obtainable through the maintenance of a higher average stove efficiency. (8) The hot-blast being practically free from abrasive dust, there is an absence of its cutting (sand-blast) action upon the linings of the hot-blast connections and of the iron and steel fittings where blast leaks are liable to occur.

The very large volumes of blast used in modern blast-furnace practice naturally necessitate stoves of much greater heating surface than is required in the older practice. The modern hot-blast stove is, therefore, constructed with a heating surface of 70,000 sq. ft. to 85,000 sq. ft.; checker openings are from 3 in. to 4 in. in diameter or square, enclosed in a shell 20 ft. to 22 ft. in diameter and from 95 ft. to 110 ft. in height. There are usually four stoves per furnace, though in some cases seven stoves are provided for two furnaces, one being arranged so that it may be used on either furnace. This is open to the objection that the two furnaces may at times both need the extra stove to the probable disadvantage of one. Each furnace should have its own complete equipment when both are in operation. The stove shells and their fittings and connections must be of considerably greater strength than in the older constructions to withstand the higher pressures they are subject to, and the latter of ample area to accommodate freely the large volume of air and gas passing through them.

A small but important feature in modern blast-furnace equipment is the blast temperature regulating pipe, which consists of a connection between the cold- and hot-blast mains. The purpose of this connection is for admitting cold-blast direct into the hot-blast main to enable the regulation of the blast temperature, usually downward, when required. The cold-blast connection may be made at any convenient point in the cold-blast main, but the connection into the hot-blast main should be at the furthest possible point from the furnace to intercept the blast from the nearest stove, in order that the cold- and hot-blast may have as much time as possible to mix thoroughly, as otherwise there is danger of the cold- and hot-blast entering the bustle pipe, or circular main, from which the tuyere connections are fed, not thoroughly mixed, when some of the tuyeres will receive blast of higher temperature than others with consequent uneven working of the furnace.

3. The Raw Material Supply Plant.—While unquestionably economy in the cost of handling the raw materials for supplying the furnace has grown to be a first consideration in the design of the plant under this heading, particularly in recent years of high labour costs, the original incentive to the adoption of mechanical handling was rather one of necessity. The rapid increase in blast-

furnace outputs necessitated such large quantities of materials that they could not be efficiently handled, if at all, by the older methods of manual labour. It was therefore necessary to install mechanical charging devices. Labour displacement rather than necessary labour saving was the primary incentive, though the latter was undoubtedly recognised as an important consideration.

A very important labour-saving feature is that the raw materials shall be delivered to the works, when by rail, in self-discharging hopper wagons of as large capacity as possible, with "one-man" opening and shutting doors; when by sea direct from the ship, by means of large capacity grabs to a transfer travelling bridge, which delivers the material so received direct to the furnace bins, to the stockyard situated adjacent to the bins, and directly under the transfer bridge, or into railway wagons. The bins usually consist of a double row of slanting bottomed enclosures, constructed of steel or concrete, varying in number according to varieties of ores used, and running usually in a direction perpendicular to the length of the transfer bridge, the inclination of the bottom being towards the centre line between the two rows of bins and at an angle somewhat greater than the angle of repose of the materials. The bins are each of moderate capacity, but in total capacity usually sufficient to supply the furnace for from 48 hours to 72 hours only, as by means of the transfer bridge ample facilities are at hand to keep them filled from the stock piles if necessary. Each row of bins forms the support for a standard gauge railway track for conveying to and discharging into the various bins such materials as are received in railway wagons. A transfer car also runs on this track, or on a separate track supported by the bins, for distributing the materials delivered by the transfer bridge from the stock piles or direct from the ships. The railway wagons are elevated to the roads over the bins, either by an electric lift, or over an incline where there is sufficient room, the wagons descending to the ground level either over the same incline or a similar one at the other end or by means of a wagon drop.

Below and on the centre line between the double row of bins there runs an electric transfer car for conveying the materials from the bins to the hoist skip or bucket. The materials are discharged from the bins by gravity into a receptacle on the transfer car, through suitably controlled openings situated at the lower limit of the inclined bottoms of the bins. The transfer car also carries as an integral part of it a weighing machine, upon the beams of which rests the receptacle for receiving the materials from the bins, so that any predetermined weight of material may be discharged into the transfer car receptacle from any particular bin. The whole of the operations in connection with the transfer car are carried out by the driver of the car, whose position is such that he has under his control and observation the discharge of the materials from the bins, the weighing of the materials, and the driving of the car. The capacity of the transfer car is such that it can deliver in each trip a quantity equal to the maximum load of the hoisting skip or bucket.

Various means are in use for assuring that the materials are well distributed as they discharge into the transfer car receptacle. From this receptacle the materials are discharged through a suitably controlled door in the bottom into the hoist receptacle, or, as in some arrangements, the transfer car receptacle is hoisted direct from its seat on the car to the top of the furnace.

Several methods of hoisting the materials to the top of the furnaces are in use in modern blast-furnace equipment, which may be divided into two classes—the skip inclined hoist and the tub or bucket hoist, the latter consisting of either an inclined bucket hoist, or a vertical bucket hoist with a horizontal transfer bridge at the top. As usual where several methods are in use for doing the same thing, engineers and operators differ as to which provides the greatest number of desirable features for its purpose. As far as this paper is concerned, however, the purpose is the same in each method, and the author does not, therefore, propose to enter into a discussion of their relative merits.

That purpose is obviously to deliver the solid raw materials required in the production of pig iron to the top of the furnace, and to distribute them as uniformly as possible on and around the furnace charging bell. This is a feature of the greatest importance, as has been shown in the discussion of the question of distribution under section I on "Preparation of Materials."

4. The output disposal plant. The principal output from a blast-furnace is, of course, pig or molten iron, the others being slag and gas. With modern blast-furnace equipment the pig, or casting, bed has ceased to exist as an essential part of the furnace equipment, the whole of the output being run into ladle cars of varying capacity, from the simple open top type of 30 or more tons to the large enclosed type of 100 or more tons capacity, though in some cases even the use of hot metal ladle cars is eliminated, as will be described later in connection with the casting machine. When the molten metal is taken to the steelworks receiver or mixer there is an end of it as far as the blast-furnace is concerned, excepting when the quality is not satisfactory to the steelworks manager. When all or any portion of the output is required in the form of pigs, the molten metal is run into ladle cars for conveyance to a casting machine, which is usually located at some point away from the furnace, convenient to railway connections, or as in some more recent arrangements, the casting machine is located adjacent to the furnace, the molten metal being run direct into a receiver from which it is teemed into the casting machine feeding troughs, thus eliminating the necessity for hot metal ladle cars, except for such molten metal as is required for steel-making.

Though several types of pig-casting machines have been designed, the original or Uhling design, with various modifications and improvements for handling the molten and cold metal, is the type most usually installed at present. This machine consists of an endless chain of cast-iron moulds of about 100 lb. capacity each, and of a shape to allow a free discharge of the cold metal. The moulds are key bolted to a flexible frame carried on small flanged wheels which run on an inclined way rising from the pouring end. The molten metal is poured from the ladles, which are tilted by a power device, into a shallow basin from which it runs through feeding troughs into the moulds as they rise slowly from their return journey and pass under the discharge end of the troughs. To prevent the molten metal burning or sticking to the moulds, they are coated with a solution of limewater, which is sprayed upon them as they return to the pouring end upside down, under the machine, the limewater being blown upward by air jets in the lime tank. Owing to the heat of the moulds they quickly dry in readiness for the molten metal before they reach the feeding troughs. At the upper end of the train of moulds as they turn over to begin their return journey, the metal, which by this time has solidified (the incline is designed of sufficient length for this purpose), freely falls from the moulds on to a chute from which it discharges either direct into steel-bodied wagons where it is water-sprayed for cooling, or on to an inclined travelling endless plate conveyor which passes with its burden of hot pigs through a water-filled tank of a length sufficient to cool the pigs below the ignition point of wood. At the upper end of the conveyor as it turns for the return journey the cold pigs slide off into a chute and are discharged into railway wagons. Machines are built single strand or multiple strand according to the capacity required, each strand consisting of a single chain of moulds having a capacity of roughly 500 tons per 24 hours.

While the structural parts of these machines were formerly built entirely of steel they are now constructed of ferro-concrete, owing to its more lasting qualities and lower cost. In addition to the necessary facilities which it provides for casting the large outputs of the modern blast-furnace, the pig-casting machine, the successful and satisfactory operation of which has been thoroughly demonstrated through many years of use, has very much simplified the handling of molten pig-iron by eliminating the many objectionable features of the older method of casting in sand beds, and breaking by hand or by hydraulic or electrical pig-breaking machines, besides effecting considerably economy of labour and saving in waste.

The disadvantages of sand-bed casting and the advantages of the machine method of handling molten pig iron may be enumerated as follows:—

Disadvantages of the sand-casting method:—(1) Difficult and high-priced labour required; (2) large quantities of clean sand required; (3) imperfect results, core jumps, plated beds, irregular breaking, and irregularity in sizes of pigs and sows; (4) heavy waste in runner scrap; (5) slower melting of sand-covered pigs, and cost of melting the sand on the pigs, in the steel furnace; (6) deleterious effects of sand-covered iron in basic steel furnaces.

Advantages of the pig-casting machine method:—(1) Immediate removal of molten metal from the immediate vicinity of the blast-furnace. (This, of course, does not apply where the metal is run direct into a receiver adjacent to the furnace, as above described; but the author believes this arrangement has not yet been widely adopted, and is of opinion that, notwithstanding the slight extra cost of ladle cars, it is better to remove the molten metal to a safer distance, in view of the disturbances which sometimes occur in the immediate vicinity of blast-furnaces through breakouts, explosions, &c.); (2) practically no manual labour required; (3) sand-free iron; (4) uniform size of pigs of iron, and no heavy sow pieces; (5) facilities for disposal of the output always in readiness; (6) great reduction in runner scrap produced when casting; (7) saving in labour charges; (8) no core-jumps or plated beds (unsaleable iron requiring extra labour for breaking and handling); (9) a difficult and very trying class of labour is dispensed with; (10) where week-end iron only is cast, the difficulty of finding special labour for these days only is eliminated.

A discussion of this heading would not be complete without reference to the slag and gas, both of which form part of the furnace output.

While there are no special methods of slag disposal which may properly be said to apply particularly to modern blast-furnace practice, it may not be amiss to refer to some of the methods in use at modern plants. The most usual method is, of course, that which is now generally used at all, except the oldest layouts (where the slag is still run into beds, allowed to cool, then broken by hand or drop ball, and shovelled into wagons), that is, by means of large capacity, self-discharging, mechanically operated slag ladle cars, in which the slag is conveyed to some point more or less distant to get it out of the way. Where, however, recovery of the slag is desired for special commercial purposes, special methods are used, such as blowing steam through the molten slag for the production of slag wool; running the molten slag into tanks of water for granulating for cement making or other uses; running into special receptacles and cooling in layers for producing the solid product for concrete making, &c. As stated, these processes are for special purposes, and do not apply generally.

With regard to the gas there are a few points also which may be mentioned. In view of the large volumes of gas produced in modern furnaces with large outputs, it is of great importance that ample areas shall be provided in the gas out-takes at the furnace top, not only to provide for the large volume of gas to be discharged through them, but also to reduce its velocity to a minimum, in order to lessen as much as possible the tendency for the smaller particles of solid materials to be mechanically carried out with the gas. For this purpose it is usual to provide four equally distant outlets of the largest size consistent with structural safety. These outlet connections are inclined as steeply as possible upward, and are carried well above the furnace top before the gas is admitted to the downward connections, in order that any larger materials, which may at times be projected from the furnace, may fall back into it and not enter the downtakes. In some designs baffles are placed in the elbow of the uptakes in such a position that they will intercept these heavier pieces, thus avoiding the necessity for carrying the uptakes so high. A further reason for the multiple equidistant outlets is to prevent any tendency of the gases in the upper portion of the furnace to channel towards one side, as they tend to do in older furnaces with one outlet, thus reducing the active area in the upper reducing zone of the furnace.

IV.—METHOD OF OPERATION.

In the foregoing the author has endeavoured to define in some detail those factors which enter into, and make possible, modern blast-furnace practice. They are the elements out of the adoption of which that practice has developed. He has therefore designated them "The Bases of Modern Blast-Furnace Practice."

Certain operative features have necessarily been referred to in connection with the discussion of these factors; but so many of the details of operation, or management of a blast-furnace, are based on practical knowledge, acquired only by years of experience and common sense, that any detailed discussion of them is not possible in a paper of this nature. It would not, however, be complete without some reference to an essential difference in the method of operation by which the improvements in results, made possible by the introduction of these factors, are obtained, and the method of operation still prevalent in many localities where modern practice has not been adopted. In modern practice the nearest possible approach to uniformity in all controllable factors is a first principle in order to obtain the nearest possible approach to uniformity of action within the furnace. Reference has already been made to the importance of this question of uniformity in various connections, including uniformity or regularity of blast volume, irrespective of furnace pressure or resistance. In the older practice just referred to as still prevalent in many localities, the volume of blast is varied with the furnace resistance, that is, the varying conditions within the furnace are permitted to cause lack of uniformity or irregularity in the volume of blast delivered to the furnace. This method being contrary to the principle of uniformity of all controllable factors is totally inapplicable to modern practice. As the principle involved in the comparison of these two methods of operation were outlined in some detail in the author's evidence before the Iron and Steel Industries Committee, he will not state them here. Suffice it to say that blowing by constant volume irrespective of furnace resistance is the method of operation essentially employed in modern blast-furnace practice. The actual volume of blast per minute, the number, size, and length of projection of the tuyeres inside the crucible walls, the weight of coke per pound of charge, the rotation of coke, ore and flux in the charge, the degree of bosh wall cooling, &c., are all operating conditions determinable, for any particular furnace and set of materials, within certain limits by experience only.

## TESTS OF MONEL METAL.

THE acid resisting qualities of Monel metal would appear to be appreciated better elsewhere than in this country if we may judge by the uses to which this material is now frequently put. It has been adopted to a considerable extent in connection with bleaching and dyeing for essential parts of machines liable to be adversely affected by the liquors used. It has been applied to centrifugals, and to centrifugal pumps handling acid and alkali solutions, and so on. In connection with superheated steam, and high temperature work, the material often presents advantages over brasses and bronzes, as in addition to its powers of resistance to erosion and corrosion, it retains a good proportion of its full strength in the higher ranges of temperature.

Its resistance to erosion has recently been brought out in a test, of which Messrs. G. and J. Weir Limited, of Cathcart, Glasgow, have sent us particulars. Messrs. Weir are sole concessionaries for this material in Great Britain. In this test a number of ¼-in. nozzles of different metals were inserted in a pipe in an enclosed tank. Opposite each nozzle was arranged a disc of the same material. The pipe was coupled to a direct-acting pump which drew water from the bottom of the tank and supplied it to the pipe at a pressure of 250 lb. per square inch. Air was admitted to the pump cylinder by a snifting valve to an extent which caused the piston to jump 1 in. of its stroke. The water was maintained at a temperature of 150 deg. Fahr., and analysis gave its quality as follows:—Calcium chloride, 14 grammes per gallon; sodium nitrate, 5 grammes per gallon; sodium chloride, 20 grammes per gallon; magnesium chloride, 2·5 grammes per gallon; gritty matter 26 grammes per gallon—thus representing a bad feed water. The pump was worked for 500 hours, after which a photograph was taken of the effect of the jets on the discs. The amount of metal removed was too small to gauge accurately, but the appearance of the specimens enables them to be classified with rolled Monel metal at one end of the scale, and mild steel right at the bottom of the list. A Monel bronze, formed by adding copper to Monel, came second; a nickel bronze third. The Monel specimen had an analysis of Cu, 28; Ni, 69; Fe, 2; while the two other specimens named gave about Ni, 30; Cu. 68, with percentages of Sn, Al and Mn. Phospor and aluminium bronzes, &c., came lower on the list.